Education and income-based inequality in tooth loss among Brazilian adults: does the place you live make a difference?

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Abstract
Background: Socioeconomic inequalities in tooth loss might be minimized or potentialized by the characteristics of the context where people live. We examined whether there is contextual variation in socioeconomic inequalities in tooth loss across Brazilian municipalities.

Methods: Data from the 2010 National Oral Health Survey of 9,979 adults living in 177 Brazilian municipalities were used. Education and household income were used as the individual socioeconomic indicators. At the municipal level, we used the Municipal Human Development Index as our contextual indicator of socioeconomic status (low:<0.699 versus high: >0.70). The Relative Index of Inequality (RII) and the Slope Index of Inequality (SII) were calculated to compare the magnitude of education and income-based inequalities among municipalities with low versus high HDI. Multilevel Poisson regression models with random intercepts and slopes were developed.

Results: At the individual level, adults with lower education & income reported more tooth loss. The mean number of lost teeth was 9.62 (95%CI: 8.02-11.23) and 7.03 (95%CI: 6.52-7.55) in municipalities with low and high HDI, respectively. Municipalities with high HDI showed higher relative and absolute education-based inequality. For income-based inequalities, higher SII was observed in municipalities with lower HDI. A significant cross-level interaction indicated that high-education adults reported fewer lost teeth when they lived in municipalities with high HDI compared to adults with the same education level living in low HDI municipalities. For individuals with the lowest education level, there was no difference in the number of teeth between those from municipalities with high and low HDI.

Conclusions: There was a social gradient in tooth loss by education and income. Living in disadvantaged municipalities cannot overcome the risk associated with low schooling. The protective effect of higher education can be reduced when people live in disadvantaged areas.

Background
Tooth loss is an important oral health problem with consequences for physical and psychosocial health as well as quality of life [1-3]. It is a good proxy for the cumulative oral health status of individuals [4], summarizing the impacts of adverse circumstances throughout the life course [5]. The
extent of tooth loss is highly sensitive to socio-demographic, psychosocial and behavioral factors at both contextual and individual levels. Despite a significant decline in the prevalence and incidence of severe tooth loss in the past two decades [6], socioeconomic inequalities in this condition persist across the globe, including Brazil [4, 7-10].

Socioeconomic inequalities in tooth loss have been studied extensively at the individual level [11-14], with education and income being the most common measures of socioeconomic position. These two measures, although moderately correlated, represent distinct socioeconomic domains, with potentially different pathways or mechanisms linking them to health [15].

Although previous studies have shown a consistent social gradient in tooth loss [11-13, 16-20], explanations using only individual-based approaches neglect population variations in oral health as well as potential contextual influences [21, 22]. Over and above individual socioeconomic status, the places where people live might be related to oral health outcomes [21]. Multilevel analyses have been used to investigate the influence of geographical areas on oral health after accounting for individual-level factors (compositional effect) [21, 23] addressing confounders at two or more levels of social organization. The persistence of an independent area effect suggests that characteristics about the area itself are important to the health of its residents (contextual effect) [22].

Several studies among adults [16-19, 24-26] and elders [27] have used a multilevel approach to evaluate the area effect on tooth loss [16-19, 24-32]. In general, these studies had shown higher tooth loss in disadvantaged areas independently of individual socioeconomic indicators [23]. Contextual effect of living in the disadvantaged area on tooth loss have been explained by higher barriers to access the dental services, worse urban structure (treated water), more stress and lower community social capital [23, 25, 27, 30, 31]

In all these studies, it was assumed that the association between individual socioeconomic variables and oral health outcomes are fixed across areas (random intercepts and fixed slopes). However, area factors may not affect every income and education group in the same manner [33]. Hence, it is reasonable to allow the association of education and income with oral health to vary across areas, i.e., allow the slopes to vary.
The assumption that area influences are the same for all people may obscure significant contextual effects that affect specific groups of people. In such cases, the heterogeneity of the area can only be properly identified when random slopes are taken into account, and the variances are calculated as a function of individual characteristics [34]. Indeed, this approach has been mentioned as a way to improve the use of multilevel models to understand oral health inequalities [21].

Beyond the interest in examining whether an individual level association (e.g. between educational level & tooth loss) varies between areas, an additional consideration is whether differences in tooth loss exhibit the same magnitude among people with different levels of education and income (i.e. cross-level interactions). The investigation of cross-level interaction has public health significance, since socio-economic diversity may minimize or potentialize the adverse oral health consequences of those living in an area with concentrated disadvantage [35].

The aims of this study were therefore: i) to evaluate income and education-based inequalities in lost teeth comparing Brazilian municipalities with high and low Human Development Index (HDI); ii) to investigate the association between tooth loss and socioeconomic indicators on individual (income and education) and area (HDI) levels; iii) to determine if the social environment modifies the relationship between income/education and tooth loss. We hypothesized that tooth loss would be inversely associated with an individual’s household income and education, but that the magnitude of the association would be more pronounced in affluent municipalities (high HDI) than in poor municipalities (low HDI).

**Methods**

Data from the present analysis came from the 2010 National Oral Health Survey (SB Brazil 2010) conducted by the Brazilian Ministry of Health in Brazilian urban areas [36] between February and November 2010. The sample was obtained through the random selection of municipalities and census sectors, via multi-stage cluster sampling with probability of selection proportional to population size. Detailed information on the methods is found in other publications [37, 38]. Data for adults aged between 35 and 44 years were used in this study.

Individual interviews using a structured questionnaire was used to obtain demographic and
socioeconomic characteristics. Oral health examinations were conducted in people’s homes by calibrated dentists (kappa>0.65) under natural light following the guidelines of the WHO manual for epidemiological studies [39]. The DMFT (Decayed, Missing, and Filled Teeth) index was used to determine tooth status.

**Outcome variable**

The outcome variable was the number of teeth (discrete quantitative variable) that was missing for any reason, determined by the sum of codes 4 and 5 of the DMFT index.

**Exposures**

Education and income were used as measures of socioeconomic position at the individual level. Income was measured as total income received by all family members in the month preceding the survey (in seven categories from “R$250.00 or less” to “R$9500.00 or more”). For our analysis, the monthly household income was converted into multiples of the minimum wage, based on the current value at the time of survey (1 minimum wage = R$ 510.00, USD$303.57) and collapsed into 4 categories: up to 1, 1 to 2.9, 3 to 4.9, 5 or more times the minimum wage. Education was asked as the number of years of formal schooling and classified as less than four years (insufficient education), 4-7 (incomplete elementary education), 8-10 (completed elementary, but incomplete secondary education), and 11 or more (completed secondary, incomplete university education, or college graduate).

We used the Municipal Human Development Index (HDI) as an indicator of municipal area SES. The Brazilian HDI considers three dimensions: Longevity, Education (access to knowledge) and Income (standard of living) [40]. The HDI was obtained from the 2013 Brazil Atlas of Human Development, which allows a selection based on data extracted from the 2010 demographic census and was classified as low (<0.699) versus high (>0.70).

**Covariates**

The covariables at individual level were age (adult: 35-39 and 40-45 years old), sex (female, male), race/skin color (white, black, yellow and brown/Ameridians), time since the last dental visit (< 12
months, between 1 and 2 years, > 3 years, did not visit). At the contextual level, we included the presence of fluoridated water supply (present or absent). The data regarding fluoridation was obtained on the National Basic Sanitation Survey performed by the Brazilian Institute of Geography and Statistics (IBGE) in 2008 [41]. We also included the estimated coverage of the population by primary care oral health services, which corresponds to the mean monthly number of primary care oral health teams for every 3000 individuals to the total population of the municipality in the analyzed year. Higher oral health services coverage indicated higher potential access to basic dental services. The cut off for this variable was 40% that was the goal to be achieved in the biennium 2010/2011[42]. Data about coverage were obtained from the website of the Department of Information Technology of the Unified Health System (DATASUS).

Statistical analysis

Comparison of income and education-based inequalities between municipalities with high and low HDI

Descriptive analysis was performed to obtain mean tooth loss for each municipality, and the results were shown separately according to the HDI level (high or low). The magnitude of relative and absolute educational and income-based inequalities in the tooth loss was calculated using the Relative Index of Inequality (RII) and Slope Index of Inequality (SII) for municipalities with high and low HDI. RII and SII are summary measures recommended when making comparisons across populations [43]. These indices are regression-based and take the whole socioeconomic distribution into account, rather than only comparing the two most extreme groups. For municipalities with high and low HDI, the population in each education or income category was assigned a modified ridit-score based on the midpoint of the range in the cumulative distribution of the participants in the given category. We used generalized linear models (log-binomial regression), with a logarithmic link function to calculate RII s (rate ratios) and with an identity link function to calculate SII s (rate differences) [44]. Both indices were estimated with 95% confidence intervals. The RII can be interpreted as the rate ratio and the SII can be interpreted as the rate difference at the bottom and the top of the educational or income hierarchy. If there is no inequality, RII assumes the value of 1.0. The further the value of RII from 1.0, the higher the level of inequality. RII assumes only positive
values, with values larger than one indicating a concentration of the indicator among the advantaged and values smaller than one indicating a concentration of the indicator among the disadvantaged. If there is no inequality, SII takes the value of zero. Greater absolute values indicate higher levels of inequality. Positive values indicate higher coverage in the advantaged subgroups, and negative values indicate higher coverage in the disadvantaged subgroups.

**Association between tooth loss and socioeconomic indicators**

Multilevel Poisson regression procedures with unstructured covariances matrix were used to model the two-level structure of individuals (level 1) nested within municipalities (level 2). A five-step sequential modeling strategy was adopted: i) **model 1** (empty model): a model without the inclusion of any covariates, in which the variance in tooth loss is inspected between municipalities. A significant random intercept variance indicates the presence of unexplained differences in tooth loss between municipalities. The Wald test evaluated the significance of random intercept, and the Median Rate Ratio measured the heterogeneity among municipalities, according to Austin et al. (2017) [45]. There is no variation between municipalities if the MRR is 1.0, but the higher the MRR, the greater the area-level variation. ii) **model 2 (random intercept, fixed effect)**: considers all the individual-level variables in the fixed part. This model assessed the association between tooth loss and income and education adjusted for covariables at the individual level. The variation between municipalities is allowed for, conditional on the individual, compositional factors. iii) **model 3**: as model 2, but including the municipalities-level variables. The proportional change in variance (PCV) was calculated according to Merlo et al. (2005) [46], using the following formula: PCV = (variance model 1 - variance model 2)/variance model 1. iv) **model 4 (random slope and random intercept model)**: as model 2, but the model allows both the intercept and slope to be random parameters. Therefore, each municipality has its own intercept and slope in which the variability from the overall intercept and slope can be investigated with the addition of individual and municipality variables and their interactions (cross-level interactions). Random slopes for education and income were considered. The comparison of goodness fit between model 2 and model 4 was performed using the LR-test. v) **model 5**: as model 4, including the municipalities-level variables, in which the cross-level interactions between
education/income and HDI were considered. The interaction term represents the change in the slope of education/income on tooth loss across municipalities when HDI changed from low to high. The estimated mean of lost teeth according to individual socioeconomic variables for municipalities with high and low HDI was demonstrated using a graph of the predicted model. Procedures for complex sample design were used to calculate age- and sex-adjusted estimates of the outcomes, SII and RII. Statistical analyses were performed using STATA version 15.0 (StataCorp LP, College Station, Texas, USA).

The Brazilian National Council of Ethics in Research approved the SBBrazil 2010 study, protocol no. 15498, January 7, 2010.

Results

The sample was 9979 adults, residing in 177 municipalities. The characterization of the sample and mean of lost teeth according to investigated variables are shown in table 1.

Table 1

| HDI  | RII     | 95% Confidence Interval | HDI  | RII     | 95% Confidence Interval |
|------|---------|-------------------------|------|---------|-------------------------|
| Low  | .4145292| .2730278-.6293661       | Low  | .43582  | .294345-0.6453145       |
| High | .257864 | .0204196-.325636        | High | .400134 | .313059-0.511428        |

Figure 1

The value of RII and SII shows a higher number of tooth loss in disadvantaged groups (lowest education and income levels). Higher relative and absolute education-based inequality were observed among municipalities with high HDI. For income-based inequalities, higher SII was observed in municipalities with lower HDI (Table 2).

Table 2: Education and income-based inequalities in municipalities with low and high HDI

| HDI  | Education-based inequality | Income-based inequality |
|------|-----------------------------|-------------------------|
|      | RII  | 95% Confidence Interval    | RII  | 95% Confidence Interval    |
| Low  | .4145292 | .2730278-.6293661       | Low  | -.808665 | -11.1723-5.00103 |
| High | .257864 | .0204196-.325636        | High | -.76439 | -10.1242-7.40459 |
*SII: Slope Index of Inequalities and RII: Relative Index of Inequalities

The multilevel crude estimates showed that all individuals variables were significantly associated with tooth loss (Table 3).

Table 3

Table 4 shows the multilevel models assuming random intercept and fixed effects. The empty model shows that the area level variation was significant, suggesting differences in tooth loss among municipalities (LR test: chi2 = 7456.66; Prob >= chibar2 = 0.0000), and the MRR (1.54) also indicated variation across municipalities. The MRR, as well as the between-municipality variance, come down from 20.52 to 14.74 (-28.1%) after the inclusion of individual variables (compositional differences) (Model 2) (Table 4). In model 3, assuming fixed effects, a social gradient in tooth loss for income and education was observed. Municipalities with high HDI presented a lower number of tooth loss (IRR: 0.87, 95% CI: 0.77-0.99). The inclusion of municipalities level variables represented an additional 15.2% decrease in variability of tooth loss among municipalities (Table 4).

Table 4

Table 5 shows the models whereby the nature of between-municipalities variation is modeled as a function of individual education (random slope). The Likelihood-ratio Test showed that model 4 presented a better fit than model 2 (Likelihood-ratio test: 1201.74, Prob > chi2 = 0.0000), justifying this modeling step. The high-education groups not only have a lower number of tooth loss but also more variance (variance: 0.566 (0.400,0.801) (Table 5). The graph of fitted lines shows how the municipal variation is more pronounced among individuals with higher education (Figure 2).

Model 5 shows that when the association between education and tooth loss was allowed to vary across municipalities, the main effect of HDI was not significant. The social gradient in tooth loss by individual income and education continue to be observed. Municipalities with fluoridated water showed a lower number of lost teeth (Table 5).

Table 5

Figure 2

The cross-level interaction between education and HDI was significant, indicating that the association between these two variables is not constant across municipalities, with steeper slopes observed in municipalities with high HDI. There is some evidence that the number of lost teeth is lower for the high-education group when they live in municipalities with high HDI compared with those with the same education level living in municipalities with low HDI. For individuals with the lowest education level, there was no difference in the number of teeth comparing those from municipalities with high versus low HDI. When the variation was modeled as a function of individual income, the cross-level interaction between individual income and HDI was not significant. (Figure 3).
For parsimony, the models were adjusted with a random slope for education. The fixed effect of individual and contextual variables did not change with the inclusion of cross-level interactions (Table 6).

Table 6

Figure 3

Discussion

The tooth loss represents an “end state” in oral health, and the present study reaffirmed the persistent concentration of tooth loss among the most disadvantaged individuals. Over and above individual disparities, our findings also demonstrated that the magnitude of educational and income-based inequalities varied between municipalities with high versus low HDI. Our results showed that educational attainment was “less protective” against tooth loss when people live in disadvantaged areas. Conversely, adults with the lowest levels of education and income had greater tooth loss regardless of whether they lived in a municipality with high or low HDI.

Our study replicated the inverse association between socioeconomic status and tooth loss after adjusting for all covariates at the individual and municipality level [11–13]. Using different outcomes related to tooth loss (<9 remaining natural teeth; lack of functional dentition/ inadequate dentition: \(\leq 21\) natural teeth; count of tooth loss or remaining teeth and edentulousness), previous studies have consistently shown more tooth loss among the more disadvantaged groups. Quasi-experimental evidence that worsened economic circumstances (measured by subjective economic deterioration or housing damage due to disaster damage) are associated with tooth loss was provided by a natural experiment following exposure to the 2011 Great East Japan Earthquake and Tsunami [47]. A meta-analysis of 10 cohort studies and two cross-sectional studies found a significant association between low income and tooth loss [14]. Those living in poverty suffer a greater burden of oral diseases, such as dental caries and periodontitis [48, 49], the main causes of tooth loss in adults. They also have a higher prevalence of systemic conditions, such as diabetes, cardiovascular disease, and obesity [50, 51], that are related to tooth loss. Besides these biological explanations, the conceptual mediators of the effect of SES on oral health include material deprivation, psychosocial distress, and behavioral factors. Low income may make it impossible to access healthy food, oral health services, and
preventive resources. Education can equip individuals with specific knowledge and skills that are useful for disease prevention. Psychosocial mechanisms may also apply, i.e., “the effects of income and education on health are mediated through symbolic resources such as status, prestige, and control within a community” [15, 52]. A previous study showed that income might affect tooth loss through “stress-induced oral-health-related behaviors” and psychological effects, since a relationship between those factors and tooth retention may exist [53].

In addition to those factors, it has been demonstrated that economic constraints are associated with the type of dental treatment delivered. While subjects in the lower income brackets are more prone to dental extraction, individuals with higher income are more likely to seek periodic routine appointments and conservative dental treatment, resulting in a higher number of retained teeth [54, 55]. In Brazil, the higher tooth loss associated with socioeconomic disadvantage can result from systemic factors associated with the organization and delivery of oral health services. The national oral health policy, also known as Smiling Brazil (“Brasil Sorridente”), was implemented only in 2004, ensuring universal coverage [56]. This policy increased the access of adults to oral health services, who historically had significant ongoing unmet needs with only urgent care available in public services [56]. The lack of access to restorative and preventive services in public health services may have contributed to tooth loss, especially among the most disadvantaged individuals. Moreover, previous studies have shown that a change in access to oral health services does not necessarily result in reduced oral health disparities because it takes time for people to change their behaviors, e.g. seeking periodic preventive dental services [57].

Our results also showed differences in tooth loss inequalities according to municipal HDI, with higher absolute and relative education-based inequality found in municipalities with high HDI and higher absolute income-inequality found in municipalities with low HDI. That is, the association between education and tooth loss was not constant across Brazilian municipalities. The significant cross-interaction term reveals that the magnitude of the association between education and tooth loss was lower in municipalities with high HDI. This result suggests that contextual factors may weaken the potential protective effect of schooling at the individual level. Low HDI municipalities in Brazil are
smaller cities with lower wealth, higher rates of urban violence, lower sanitation conditions, and urban infrastructure. These contextual aspects may represent fewer opportunities for healthy living for its residents (less access to health services, less availability of diversified healthy food, fewer leisure options, less culture, and social capital). The same contextual factors have been pointed out as determinants of oral health [21, 23] in previous studies that had demonstrated the main effect of social-level indicators on tooth loss using multilevel approaches in Brazil, United States, European countries, Australia and Japan [16–19, 24–30, 32]. Our result shows that where one lives has an effect on oral health and that this effect must be evaluated considering the characteristics of the people. The analysis performed in this study is advancing, as it may contribute to more targeted policies for the groups with the greatest need, in specific contexts.

The only significant contextual factor we found was the fluoridation of the water supply. Individuals living in municipalities with water fluoridation presented lower tooth loss. The importance of this intervention was previously shown in maintaining functional dentition [24] and tooth retention [26]. Natural experiments applied in oral health context from Brazil showed that adults who accessed fluoridate water < 50% of their lifetime presented a higher mean rate ratio of DMFT index compared with those living > 75% of their life with residential access to fluoridated water. Longer residential lifetime access to fluoridated water was associated with less dental caries, even in a context of multiple exposures to fluoride [58].

Our models were intentionally parsimonious, adjusting only for key covariates. As with most multilevel studies, our choice of area-unit (municipalities) was made for reasons of sampling and analytic convenience rather than being underpinned by an explicit theory linking area disadvantage and oral health; hence associations among these variables are likely to be underestimated. We used cross-sectional data where the distinction between current and past exposures cannot be made. Similarly, income can change throughout the life resulting in upward and downward social mobility. On the other hand, education is a socioeconomic indicator that captures the long-term influences of both early life circumstances on adult health, as well as the influence of adult resources (for example, through employment status) on health.
Conclusions
There was a social gradient in tooth loss by education and income. Living in disadvantaged municipalities cannot overcome the risk associated with low schooling. The protective effect of higher education can be reduced when people live in disadvantaged areas.

Implications for policy derived from this study mainly concern establishing and maintaining support systems for the most vulnerable individuals with low education and income. The persistent inequality demands for innovative strategies and policies that address the wider social determinants of health. These policies must protect oral health as a human right through, strengthen intersectoral strategies for poverty reduction; supporting scientific research on the health social determinants; interact communities with public health managers and researchers; support community actions to promote oral health and eliminate barriers of access to oral health care.

List Of Abbreviations
HDI - Municipal Human Development Index
RII - Relative Index of Inequality
SII - Slope Index of Inequality
DMFT - Decayed, Missing, and Filled Teeth
IBGE - Brazilian Institute of Geography and Statistics
DATASUS - Department of Information Technology of the Unified Health System
MRR - Median Rate Ratio
PCV - Proportional change in variance

Declarations

Ethical approval and consent to participate: The Brazilian National Human Research Ethics Committee approved the 2010 NOHS under process number 15,498 on July 1st, 2010. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in this study.

Consent for publication: Not applicable
Availability of data and materials: The datasets analyzed during the current study are available in the Ministério da Saúde under request.

Competing Interests: The authors RCF is a member of the editorial board of the BMC Oral Health.

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Authors' contributions: RCF analyzed and interpreted the data, wrote the manuscript. MIBS, LGR, FLC and AEBLM contribute to data analysis and interpretation. IK was the study supervisor, made substantial contributions to: data analysis and interpretation and made critical review of the intellectual content. All authors read and approved the final manuscript.

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References
1. Dioguardi M, Gioia GD, Caloro GA, Capocasale G, Zhurakivska K, Troiano G et al. The Association between tooth loss and Alzheimer's Disease: a systematic review with meta-analysis of case control studies. Dent J. 2019;7:E49.

2. Koka S, Gupta A. Association between missing tooth count and mortality: A systematic review. J Prosthodont Res. 2018;62:134-51.

3. Haag DG, Peres KG, Balasubramanian M, Brennan DS. Oral conditions and health-related quality of life: a systematic review. J Dent Res. 2017;96:864-74.

4. Cunha-Cruz J, Hujoel PP, Nadanovsky P. Secular trends in socio-economic disparities in edentulism: USA, 1972-2001. J Dent Res. 2007;86:131-6.

5. Shen J, Listl S. Investigating social inequalities in older adults' dentition and the role
of dental service use in 14 European countries. Eur J Health Econ. 2018;19:45-57.

6. Kassebaum NJ, Bernabe E, Dahiya M, Bhandari B, Murray CJ, Marcenes W. Global burden of severe tooth loss: a systematic review and meta-analysis. J Dent Res. 2014;93:20S-8S.

7. Bernabe E, Sheiham A. Tooth loss in the United Kingdom--trends in social inequalities: an age-period-and-cohort analysis. PLoS One. 2014;9:e104808.

8. Wu B, Hybels C, Liang J, Landerman L, Plassman B. Social stratification and tooth loss among middle-aged and older Americans from 1988 to 2004. Community Dent Oral Epidemiol. 2014;42:495-502.

9. Elani HW, Harper S, Thomson WM, Espinoza IL, Mejia GC, Ju X et al. Social inequalities in tooth loss: A multinational comparison. Community Dent Oral Epidemiol. 2017;45:266-74.

10. Peres MA, Barbato PR, Reis SCGB, Freitas CHSM, Antunes JLF. Tooth loss in Brazil: analysis of the 2010 Brazilian oral health survey. Rev Saude Publica. 2013;47:78-89.

11. Barbato PR, Muller Nagano HC, Zanchet FN, Boing AF, Peres MA. [Tooth loss and associated socioeconomic, demographic, and dental-care factors in Brazilian adults: an analysis of the Brazilian Oral Health Survey, 2002-2003]. Cad Saude Publica. 2007;23:1803-14.

12. Jimenez M, Dietrich T, Shih MC, Li Y, Joshipura KJ. Racial/ethnic variations in associations between socioeconomic factors and tooth loss. Community Dent Oral Epidemiol. 2009;37:267-75.

13. Sabbah W, Tsakos G, Sheiham A, Watt RG. The role of health-related behaviors in the socioeconomic disparities in oral health. Soc Sci Med. 2009;68:298-303.

14. Seerig LM, Nascimento GG, Peres MA, Horta BL, Demarco FF. Tooth loss in adults and income: Systematic review and meta-analysis. J Dent. 2015;43:1051-9.
15. Kawachi I, Adler NE, Dow WH. Money, schooling, and health: Mechanisms and causal evidence. Ann N Y Acad Sci. 2010;1186:56-68.

16. Turrell G, Sanders AE, Slade GD, Spencer AJ, Marcenes W. The independent contribution of neighborhood disadvantage and individual-level socioeconomic position to self-reported oral health: a multilevel analysis. Community Dent Oral Epidemiol. 2007;35:195-206.

17. Singh A, Harford J, Antunes JLF, Peres MA. Area-level income inequality and oral health among Australian adults-A population-based multilevel study. PLoS One. 2018;13:e0191438.

18. Sanders AE, Turrell G, Slade GD. Affluent neighborhoods reduce excess risk of tooth loss among the poor. J Dent Res. 2008;87:969-73.

19. Moreira Rda S, Nico LS, Barrozo LV, Pereira JC. Tooth loss in Brazilian middle-aged adults: multilevel effects. Acta Odontol Scand. 2010;68:269-77.

20. Guarnizo-Herreno CC, Watt RG, Pikhart H, Sheiham A, Tsakos G. Socioeconomic inequalities in oral health in different European welfare state regimes. J Epidemiol Community Health. 2013;67:728-35.

21. Singh A, Harford J, Peres MA. Investigating societal determinants of oral health-Opportunities and challenges in multilevel studies. Community Dent Oral Epidemiol. 2018;46:317-27.

22. Diez Roux AV. Investigating neighborhood and area effects on health. Am J Public Health. 2001;91:1783-9.

23. Barbato PR, Peres KG. Contextual socioeconomic determinants of tooth loss in adults and elderly: a systematic review. Rev Bras Epidemiol. 2015;18:357-71.

24. Koltermann AP, Giordani JM, Pattussi MP. The association between individual and contextual factors and functional dentition status among adults in Rio Grande do Sul
State, Brazil: a multilevel study. Cad Saude Publica. 2011;27:173-82.

25. Goulart Mde A, Vettore MV. Is the relative increase in income inequality related to tooth loss in middle-aged adults? J Public Health Dent. 2016;76:65-75.

26. Barbato PR, Peres MA, Hofelmann DA, Peres KG. Contextual and individual indicators associated with the presence of teeth in adults. Rev Saude Publica. 2015;49:27.

27. Ito K, Aida J, Yamamoto T, Ohtsuka R, Nakade M, Suzuki K et al. Individual- and community-level social gradients of edentulousness. BMC Oral Health. 2015;15:34.

28. Chalub LL, Martins CC, Ferreira RC, Vargas AM. Functional Dentition in Brazilian Adults: An Investigation of Social Determinants of Health (SDH) Using a Multilevel Approach. PLoS One. 2016;11:e0148859.

29. Celeste RK, Nadanovsky P, Ponce de Leon A, Fritzell J. The individual and contextual pathways between oral health and income inequality in Brazilian adolescents and adults. Soc Sci Med. 2009;69:1468-75.

30. Koyama S, Aida J, Saito M, Kondo N, Sato Y, Matsuyama Y et al. Community social capital and tooth loss in Japanese older people: a longitudinal cohort study. BMJ Open. 2016;6:e010768.

31. Aida J, Hanibuchi T, Nakade M, Hirai H, Osaka K, Kondo K. The different effects of vertical social capital and horizontal social capital on dental status: a multilevel analysis. Soc Sci Med. 2009;69:512-8.

32. Bernabe E, Marcenes W. Income inequality and tooth loss in the United States. J Dent Res. 2011;90:724-9.

33. Subramania SV, Kawachi I, Kennedy BP. Does the state you live in make a difference? Multilevel analysis of self-rated health in the US. Soc Sci Med. 2001;53:9-19.

34. Aguinis H, Gottfredson, R. K., Culpepper, S. A. Best-Practice Recommendations for Estimating Cross-Level Interaction Effects Using Multilevel Modeling. Journal of
35. Castelli A, Jacobs R, Goddard M, Smith PC. Health, policy and geography: insights from a multi-level modelling approach. Soc Sci Med. 2013;92:61-73.

36. Brasil. SB Brasil 2010: Pesquisa Nacional de Saúde Bucal: resultados principais. In: SB Brasil 2010: Pesquisa Nacional de Saúde Bucal: resultados principais 2011. [http://bvsms.saude.gov.br/bvs/publicacoes/pesquisa_nacional_saude_bucal.pdf]

37. Silva NN, Roncalli, A. G. . Sampling plan, weighting process and design effects of the Brazilian Oral Health Survey. Rev Saude Publica. 2013;47:3-11.

38. Roncalli AG, Silva NN, Nascimento AC, Freitas CHS, Casotti E, Peres KG et al. Aspectos metodológicos do Projeto SBBrasil 2010 de interesse para inquéritos nacionais de saúde. Cad Saude Publica. 2012;28:S40-S57.

39. WHO: Oral health surveys: basic methods, 4 ed. Geneva: ORH/EPID; 1997.

40. WHO: Atlas do Desenvolvimento Humano no Brasil In.: World Health Organization; 2012.

41. IBGE. Pesquisa Nacional de Saneamento Básico [National Basic Sanitation Survey]. In: Pesquisa Nacional de Saneamento Básico [National Basic Sanitation Survey]. 2008. [https://www.ibge.gov.br/estatisticas/multidominio/9073-pesquisa-nacional-de-saneamento-basico.html]

42. Brasil. Portaria 3840. In: Portaria 3840. 2010. [http://bvsms.saude.gov.br/bvs/saudelegis/gm/2010/prt3840_07_12_2010.html]

43. Harper S, Lynch J: Methods for measuring cancer disparities: using data relevant to healthy people 2010 cancer-related objectives. Montreal: Center for Social Epidemiology and Population Health, University of Michigan; 2010.

44. Spiegelman D, Hertzmark E. Easy SAS calculations for risk or prevalence ratios and differences. Am J Epidemiol. 2005;162:199-200.
45. Austin PC, Stryhn H, Leckie G, Merlo J. Measures of clustering and heterogeneity in multilevel Poisson regression analyses of rates/count data. Stat Med. 2018;37:572-89.

46. Merlo J, Yang M, Chaix B, Lynch J, Rastam L. A brief conceptual tutorial on multilevel analysis in social epidemiology: investigating contextual phenomena in different groups of people. J Epidemiol Community Health. 2005;59:729-36.

47. Matsuyama Y, Aida J, Tsuboya T, Hikichi H, Kondo K, Kawachi I et al. Are Lowered Socioeconomic Circumstances Causally Related to Tooth Loss? A Natural Experiment Involving the 2011 Great East Japan Earthquake. Am J Epidemiol. 2017;186:54-62.

48. Costa SM, Martins CC, Pinto MQC, Vasconcelos M, Abreu M. Socioeconomic factors and caries in people between 19 and 60 Years of age: an update of a systematic review and meta-analysis of observational studies. Int J Environ Res Public Health. 2018;15.

49. Borrell LN, Crawford ND. Socioeconomic position indicators and periodontitis: examining the evidence. Periodontol 2000. 2012;58:69-83.

50. Claassen MA, Klein O, Bratanova B, Claes N, Corneille O. A systematic review of psychosocial explanations for the relationship between socioeconomic status and body mass index. Appetite. 2019;132:208-21.

51. Polzer I, Schwahn C, Volzke H, Mundt T, Biffar R. The association of tooth loss with all-cause and circulatory mortality. Is there a benefit of replaced teeth? A systematic review and meta-analysis. Clin Oral Investig. 2012;16:333-51.

52. Galobardes B, Shaw M, Lawlor DA, Lynch JW, Davey Smith G. Indicators of socioeconomic position (part 1). J Epidemiol Community Health. 2006;60:7-12.

53. Bernabe E, Watt RG, Sheiham A, Suominen-Taipale AL, Uutela A, Vehkalahti MM et al. Sense of coherence and oral health in dentate adults: findings from the Finnish
Health 2000 survey. J Clin Periodontol. 2010;37:981-7.

54. Klock KS. Patients' perceptions of the decision-making process leading to extraction of permanent teeth in Norway. Community Dent Oral Epidemiol. 1995;23:165-9.

55. Thomson WM, Poulton R, Kruger E, Boyd D. Socio-economic and behavioural risk factors for tooth loss from age 18 to 26 among participants in the Dunedin Multidisciplinary Health and Development Study. Caries Res. 2000;34:361-6.

56. Pucca GA, Jr., Gabriel M, de Araujo ME, de Almeida FC. Ten Years of a National Oral Health Policy in Brazil: Innovation, Boldness, and Numerous Challenges. J Dent Res. 2015;94:1333-7.

57. Pereira CR, Roncalli AG, Cangussu MC, Noro LR, Patricio AA, Lima KC. [Impact of the Family Health Strategy: an analysis in cities in Northeast Brazil with more than 100,000 inhabitants]. Cad Saude Publica. 2012;28:449-62.

58. Peres MA, Peres KG, Barbato PR, Hofelmann DA. Access to Fluoridated Water and Adult Dental Caries: A Natural Experiment. J Dent Res. 2016;95:868-74.

Tables
Table 1: Sociodemographic characteristics of the Brazilian adults and mean of lost teeth according to investigated variables.

|                          | Sample size | Prop. 95%CI          | Lost Teeth Mean (SE) |
|--------------------------|-------------|----------------------|----------------------|
| Individual level variables |             |                      |                      |
| Sex                      |             |                      |                      |
| Male                     | 3,374       | 36.91[33.67, 40.27]  | 6.67 (6.09,7.26)     |
| Female                   | 6,405       | 63.09[59.73, 66.33]  | 7.87 (7.24,8.49)     |
| Age                      |             |                      |                      |
| 35-40                    | 5,139       | 52.39[49.83, 54.93]  | 5.81 (5.26,6.35)     |
| 40-45                    | 4,640       | 47.61[45.07, 50.17]  | 9.21 (8.52,9.89)     |
| Household income (in the minimum wage) |             |                      |                      |
| up to 1                  | 1,420       | 12.87[11.05, 14.93]  | 10.17 (9.10,11.24)   |
| 1 to 2.9                 | 4,783       | 53.19[49.31, 57.04]  | 8.25 (7.67,8.83)     |
| 3 to 4.9                 | 1,846       | 20.74[18.39, 23.31]  | 6.06 (5.16,6.96)     |
Table 3: Results of crude multilevel regression models

| Education (in years of schooling) | N   | Mean [95% CI] | SE [95% CI] |
|----------------------------------|-----|---------------|-------------|
| > = 5 mw                         | 1,486 | 13.20 [10.79, 16.06] | 3.64 (2.95, 4.35) |
| 0 to 4                           | 856  | 10.28 [8.57, 12.27] | 12.50 (11.16, 13.84) |
| 5 to 8                           | 2,523 | 29.65 [26.41, 33.11] | 9.35 (8.62, 10.08) |
| 9 to 11                          | 4,017 | 38.25 [35.36, 41.22] | 6.64 (6.10, 7.19) |
| > 12                             | 2,297 | 21.82 [18.16, 26.00] | 3.73 (3.09, 4.36) |

| Self-reported skin color/etnia    | N   | Mean [95% CI] | SE [95% CI] |
|----------------------------------|-----|---------------|-------------|
| Black + yellow + blown + Ameridians | 5642 | 50.03 [46.25, 53.81] | 8.08 [7.50, 8.68] |
| White                            | 4137 | 49.97 [46.19, 53.75] | 6.77 [6.15, 7.40] |

| Time since last dental visit     | N   | Mean [95% CI] | SE [95% CI] |
|----------------------------------|-----|---------------|-------------|
| Never used                       | 688  | 7.14 [5.48, 9.25] | 10.13 [8.33, 11.95] |
| < 1 year                         | 1,914 | 21.38 [18.95, 24.04] | 8.62 [7.91, 9.33] |
| 1 to 2 years                     | 2,446 | 25.41 [23.19, 27.76] | 7.48 [6.79, 8.18] |
| > 3 years                        | 4,543 | 46.07 [43.53, 48.62] | 6.37 [5.79, 6.94] |

| Municipalities level variables   | N   | Mean [95% CI] | SE [95% CI] |
|----------------------------------|-----|---------------|-------------|
| Human Development Index          |     |               |             |
| Low + Medium                     | 77  | 43.50         | 9.62 (8.02, 11.22) |
| High                             | 100 | 56.50         | 7.03 (6.52, 7.55) |

| Coverage of oral health services | N   | Mean [95% CI] | SE [95% CI] |
|----------------------------------|-----|---------------|-------------|
| Below of goal                    | 91  | 51.41         | 7.04 [6.50, 7.57] |
| Above of goal                    | 86  | 48.59         | 8.39 [7.29, 9.49] |

| Fluoridation of water supply     | N   | Mean [95% CI] | SE [95% CI] |
|----------------------------------|-----|---------------|-------------|
| No                               | 59  | 33.33         | 9.57 [8.58, 10.57] |
| Yes                              | 118 | 66.67         | 7.13 [6.61, 7.65] |
| Individual level variables                                                                 | Crude Count Ratio (95% CI)          |
|-------------------------------------------------------------------------------------------|-------------------------------------|
| Sex                                                                                       |                                     |
| Male                                                                                      | 1                                  |
| Female                                                                                    | 1.18*** [1.16, 1.19]                |
| Age group                                                                                 |                                     |
| 35-39 years old                                                                           | 1                                  |
| 40-45 years old                                                                           | 1.59*** [1.57, 1.61]                |
| Household income (in minimum wage)                                                        |                                     |
| up to 1                                                                                   | 1                                  |
| 1 to 2.9                                                                                  | 0.88*** [0.87, 0.90]                |
| 3 to 4.9                                                                                  | 0.69*** [0.67, 0.71]                |
| > = 5 mw                                                                                  | 0.46*** [0.45, 0.48]                |
| Education (in years of study)                                                             |                                     |
| 0 to 4                                                                                    | 1.00                               |
| 5 to 8                                                                                    | 0.89*** [0.87, 0.91]                |
| 9 to 11                                                                                   | 0.65*** [0.63, 0.66]                |
| > 12                                                                                      | 0.41*** [0.40, 0.42]                |
| Self-reported skin color/ethnia                                                           |                                     |
| White                                                                                     | 1                                  |
| Black + yellow+ brown + Ameridians)                                                       | 1.17*** [1.15, 1.19]                |
| Time since last dental visit                                                             |                                     |
| Never used                                                                                | 1                                  |
| ≤ 1 year                                                                                  | 0.75*** [0.73, 0.78]                |
| 1 to 2 years                                                                              | 0.86*** [0.84, 0.89]                |
| > 3 years                                                                                 | 1.02 [0.99, 1.05]                   |
| Municipalities level variables                                                            |                                     |
| Municipal Human Development Index                                                         |                                     |
| Low + Medium                                                                              |                                     |
| High                                                                                      | 0.70*** [0.61, 0.79]                |
| Fluoridation of water supply                                                             |                                     |
| No                                                                                        | 1                                  |
| Yes                                                                                       | 0.75*** [0.65, 0.86]                |
| Coverage of public oral health services                                                   |                                     |
| Below of goal                                                                             | 1                                  |
| Above of goal                                                                             | 1.16* [1.01, 1.32]                 |
Exponentiated coefficients; 95% confidence intervals (CI) in brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Multilevel Poisson regression models assuming random intercept and fixed effect

| Parameters | Empty model (Model 1) | Model 2* | Model 3** |
|------------|-----------------------|----------|-----------|
| Fixed part | Crude Count Ratio (95% CI) | Adjusted Count ratio (95% CI) | Adjusted Count ratio (95% CI) |
| Individual level variables | | | |
| Constant | 8.62 (8.05, 9.23) | 8.72 (8.14, 9.35) | 10.29 (9.09, 11.65) |
| Education (in years of study) | | | |
| 0 to 4 | | 1 | 1 |
| 5 to 8 | 0.91*** (0.89, 0.93) | 0.91*** (0.89, 0.93) | |
| 9 to 11 | 0.71*** (0.69, 0.73) | 0.71*** (0.69, 0.73) | |
| > 12 | 0.50*** (0.49, 0.52) | 0.50*** (0.49, 0.52) | |
| Income (in minimum wages) | | | |
| Up to 1 | 1 | 1 | 1 |
| 1 to 2.9 | 0.96*** (0.95, 0.98) | 0.96*** (0.95, 0.98) | |
| 3 to 4.9 | 0.85*** (0.83, 0.88) | 0.85*** (0.83, 0.88) | |
| > 5 | 0.66*** (0.64, 0.68) | 0.66*** (0.64, 0.68) | |
| Municipalities level variables | | | |
| Municipal Human Development Index | | | |
| Low + Medium | 1 | | |
| High | | 0.87** (0.77, 0.99) | |
| Random part | | | |
| Area level variance (Random intercept) | 20.52*** (16.43, 25.64) | 14.74*** (11.74, 18.51) | 12.50** (9.93, 15.74) |
| PCV$^6$ | -28.1% | -15.2% | |
| Median Rate Ratio | MRR = 1.54 | MRR = 1.44 | MRR = 1.40 |

Results of Multilevel Poisson Regression Model assuming random intercept and fixed effect.

Exponentiated coefficients; 95% confidence intervals in brackets; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

$^6$PCV: Proportional change in variance. *Model 2: Adjusted for individual-level variables: sex, age group, skin color, and time since the last dental visit. **Model 3: Adjusted for individual and municipalities level variables: sex, age group, skin color, time since the last dental visit, presence of fluoridated water supply, and coverage of public oral health service above the Brazilian goal.
Table 5: Multilevel Poisson regression models with a random intercept and slope (education).
### Parameters

| Parameters                          | Model 1* Adjusted Count ratio (95% CI) | Model 2* Adjusted Count ratio (95% CI) |
|-------------------------------------|---------------------------------------|---------------------------------------|
| **Fixed part**                      |                                       |                                       |
| **Individual level variables**      |                                       |                                       |
| Constant                            | 9.18 (8.42,10.00)                     | 10.29 (8.87, 11.93)                   |
| Education (in years of study)       |                                       |                                       |
| 0 to 4                              | 1                                     | 1                                     |
| 5 to 8                              | 0.80* (0.73,0.88)                     | 0.80*(0.72,0.88)                      |
| 9 to 11                             | 0.62*** (0.56,0.69)                   | 0.62*** (0.56,0.69)                   |
| ≥ 12                                | 0.43*** (0.37,0.49)                   | 0.43*** (0.37,0.49)                   |
| **Income (in minimum wages)**       |                                       |                                       |
| Up to 1                             | 1                                     | 1                                     |
| 1 to 2.9                            | 0.95*** (0.93,0.97)                   | 0.95*** (0.93,0.97)                   |
| 3 to 4.9                            | 0.84*** (0.82,0.86)                   | 0.84*** (0.82,0.86)                   |
| ≥ 5                                 | 0.68*** (0.66,0.71)                   | 0.68*** (0.66,0.71)                   |
| **Municipalities level variables**  |                                       |                                       |
| Municipal Human Development Index   |                                       |                                       |
| Low + Medium                        |                                       |                                       |
| High                                |                                       | 0.93 (0.83,1.05)                      |
| Fluoridation of water supply        |                                       |                                       |
| No                                  |                                       |                                       |
| Yes                                 |                                       | 0.85** (0.75,0.96)                    |
| Coverage of public oral health services |                                 |                                       |
| Below of goal                       |                                       |                                       |
| Above of goal                       |                                       | 1.07(0.96,1.19)                       |
| **Random part**                     |                                       |                                       |
| Constant                            | 0.197 (0.138,0.254)                   | 18.48(13.60,25.11)                    |
| Education 5-8 years of study        | 0.296 (0.217, 0.403)                  | 30.38(22.23,41.50)                    |
| Education 9-11 years of study       | 0.376 (0.282,0.500)                   | 37.18(27.90,49.54)                    |
| Education ≥ 12 years of study       | 0.566 (0.400,0.801)                   | 56.76(40.11,80.31)                    |
| Covariances (standard error)        |                                       |                                       |
| Education (5-8), constant           | -0.1464 (0.0312)                     | -0.1505(0.0317)                      |
| Education (9-11), constant          | -0.1314 (0.0316)                     | -0.1459(0.0323)                      |
| Education (>≥ 12), constant         | -0.0560 (0.0424)                     | -0.0793(0.0447)                      |
| Median Rate Ratio                   | 1.44                                  | 1.42                                  |

Exponentiated coefficients; 95% confidence intervals in brackets; * p < 0.05, ** p < 0.01, *** p < 0.001
Table 6: Multilevel regression model with a random intercept and slope (education) and cross-level interaction between socioeconomic variables

| Parameters                              | Adjusted Count ratio (95% CI) |
|-----------------------------------------|--------------------------------|
| **Fixed part**                          |                                |
| Individual level variables              |                                |
| Constant                                | 9.18 (8.42,10.00)              |
| Education (in years of study)           |                                |
| 0 to 4                                  | 1                              |
| 5-8 years of study                      | 0.75*[0.65,0.87]               |
| 9-11 years of study                     | 0.68***[0.58,0.80]             |
| > 12 years of study                     | 0.49***[0.39,0.60]             |
| Income (in minimum wages)               |                                |
| Up to 1                                 |                                |
| 1 to 2.9 minimum wage                   | 0.95***[0.93,0.97]             |
| 3 to 4.9 minimum wage                   | 0.84***[0.82,0.86]             |
| > 5 minimum wage                        | 0.68***[0.66,0.71]             |
| Contextual factors (Municipalities level)|                                |
| Municipal Human Development Index       |                                |
| Low + Medium                            | 1                              |
| High                                    | 0.93 (0.79-1.10)               |
| Fluoridation of water supply            |                                |
| No                                      |                                |
| Yes                                     | 0.85 (0.75-0.96)*              |
| Coverage of public oral health services |                                |
| Below of goal                           | 1                              |
| Above of goal                           | 1.07 (0.96-1.19)               |
| Cross-level interactions                |                                |
| HDI#5-8 years of study                  | 0.98[0.88,1.09]                |
| HDI#9-11 years of study                 | 0.77**[0.64,0.93]              |
| HDI#> 12 years of study                 | 0.63***[0.48,0.83]             |
| Median Rate Ratio (MRR)                 | 1.42                           |

Exponentiated coefficients; 95% confidence intervals in brackets; * p < 0.05, ** p < 0.01, *** p < 0.001. *Model was adjusted for individual level variables: sex, age group, skin color and time since the last dental visit.
the last dental visit.

Figures

Figure 1
Mean of tooth loss (95% CI) in each Brazilian municipality according to the HDI Legend: HDI
- Human Development Index
Figure 2

Municipalities-specific slopes of education on tooth loss Legend: Multilevel regression model with a random slope and intercept
Adjusted predicted effects of education and income on tooth loss in municipalities with low/high HDI Legend: The values of IRR to interactions terms was (HDI#5-8 years of study: 0.98(0.88,1.09); HDI#9-11 years of study (0.77**(0.64,0.93); HDI#> 12 years of study: 0.63**(0.48,0.83)). The interaction between HDI and income was not statistically significant.