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Measuring inequalities in the distribution of dental caries

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Abstract – *Objectives:* To evaluate different measurements of prevalence and inequality in the distribution of dental caries as to their partial collinearity, and ability in expressing associations with the supply of fluoridated tap water, indices of socioeconomic status and provision of dental services. *Methods:* The DMFT, the Significant Caries (SiC) Index, the proportions of children with high- (DMFT ≥ 4) and rampant- (DMFT ≥ 7) caries experience, caries-free children (DMFT $= 0$), the Gini coefficient and the Dental Health Inequality Index (DHII) were the dental outcomes appraised in a sample comprising 18 718 oral examination records for 11- and 12-year-old schoolchildren in 131 towns of the state of São Paulo, Brazil. Spatial data analysis assessed the association between aggregate figures of dental indices and several covariates. *Results:* The DMFT, the SiC Index and the proportions of children with high- and rampant-caries experience presented strong linear associations (Pearson r near or higher than 0.95), and an analogous profile of correlation with indicators of socioeconomic status, dental services and access to fluoride tap water. The same was observed for the DHII, the Gini coefficient and the proportion of caries-free children. These observations involve the perception of variables in each set as interchangeable tools for ecological studies assessing factors influencing, respectively, prevalence levels and inequality in the distribution of dental disease. *Conclusion:* An improved characterization of the skewed distribution of caries experience demands the concurrent estimation of figures of prevalence and inequality in dental outcomes. This strategy may contribute to the design of socially appropriate programmes of oral health promotion.

Key words: dental caries; dental health services; inequality; public health dentistry; socioeconomic factors

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Inequalities and their relation to living conditions are now in the mainstream of public health thinking. The extent of contemporary social inequalities led Farmer (1) to define this problem as a plague of our era. Gwatkin (2) reported the ethnic and gender dimensions of inequality, as well as the economic standing, as those that matter most for the assessment of health conditions in developing countries. In Latin America, the Pan American Health Organization (3) stated the growing impact on health and overall wellbeing of disparities associated with socioeconomic, gender and ethnic macro-determinants. These considerations underline the importance of quantitative studies addressing inequalities of health status and access to services in the Brazilian context.

Recent dental studies have developed new strategies for evaluating inequalities in dental caries distribution, in an attempt to improve the effectiveness of health actions in a context of an overall decline of caries prevalence and severity in children. Health programmes demand selective information for exploring the association of disease levels and covariates for characteristics of socioeconomic status (SES) and access to services, and for determining whether health services should be directed towards targeting individuals, areas with higher levels of dental needs or to a whole population (4). New resources on disease measurement should also contemplate enhancements in the ability of health organizations to evaluate the effectiveness of their own interventions, and perform health impact assessment (HIA) (5) so that their proposals do not inadvertently damage health or reinforce inequalities.

Tickle (6) plotted Lorenz curves for the DMFT distribution of children dwelling in seven districts in the North-west region of the UK, with the intention of evaluating strategies of oral health promotion and disease prevention programmes. The Gini coefficient is a measurement used to gauge the concentration of different variables (7, 8), mainly income, mortality and the spread of health services. It is calculated as the ratio of areas comprised under and over the corresponding Lorenz curve (9), and varies from '0' (homogeneous distribution) to a theoretic value of '1' (maximum inequality). Nugent et al. (10) argued that an equitable distribution of disease, a premise for the Gini coefficient calculation, could not be met by an integer variable such as the DMFT. In order to overcome this difficulty, they proposed the Dental Health Inequality Index (DHII), a measure based on the ratio of areas comprised under the Lorenz curves for the actual disease distribution and for a theoretical Poisson distribution with the same mean DMFT. Bratthall (11) drew his attention to the skewed distribution of dental caries in 12-year-old children, and proposed the Significant Caries (SiC) Index, calculating the mean DMFT for the one-third of the group with the highest caries levels.

São Paulo is the most populous and industrialized Brazilian state, and its scores for several indices of social development are among the highest in the country. High levels of dental caries prevalence and severity were estimated during the early 1990s by a study (12) gathering information for 237 towns in the State of São Paulo: DMFT average of 4.8 for 12-year-olds, with 40% of its towns presenting indices higher than 6.60. Caries indices were reported to have subsequently decreased in São Paulo (13) because of the fluoridation of tap water, fluoride dentifrice and a major reform of the health system. The fluoridation of water supplies has been mandatory in Brazil since 1974, but its implementation came mainly after the mid 1980s, when its population coverage exceeded 40% (14). Major dentifrice brands began selling fluoride dentifrice in 1988; the market share of fluoride dentifrice in Brazil was almost 100% during the 1990s (14). As to the reform of the Brazilian health system in 1990, it set up the dental public service in the country, which promoted initiatives on oral health education and increased the provision of dental care and preventive dental treatment to children (13). Nonetheless, reflecting the changing pattern of caries distribution in developed countries (15), the overall improvement of indices has not spread in a homogeneous way, and caries continues to present higher levels in deprived areas (16).

The present study seeks to measure both the decline and the polarization of disease. It also examines the interrelation of these two phenomena and the effect of SES indices, access to fluoride and dental service provision. Different measurements of prevalence and inequality will be compared as to their associations with these environmental factors and each other.

Methods

From August to December 1998, official agencies of the Brazilian health authority performed an epidemiological survey (17) of oral health in São Paulo, Brazil, following international standards established by the World Health Organization (WHO) (18). The examination of 87 918 schoolchildren, youngsters, adults and elderly people in 131 towns comprised dental caries, treatment needs, prosthesis, periodontosis, fluorosis and occlusion disorders. When sponsoring institutions made the survey data available for public consultation, we reviewed 18 718 oral examination records for 11- and 12-year-old children in order to estimate prevalence levels and inequalities in the distribution of dental caries. Although the survey comprised towns with different population size, and included the metropolitan area of São Paulo, the number of examined children in each town was relatively uniform because the sample size estimation ignored the correction for finite population (19).

As oral health surveys do not usually provide information about the socioeconomic characteristics of examined children, spatial data analysis was the strategy to assess covariates of caries distribution at the town level. Therefore, the present study used space as an organizing frame to explore variations in dental outcomes in different towns, by expressing single general relationships between these variables and SES indices, access to fluoridated tap water, and provision of dental services. The aggregation of variables at the town level complied with the methodology described by Bailey & Gatrell (20) for the analysis of area data. These authors defined 'spatial data analysis' as the study of observational data available for some process operating in space, and methods seeking to explain or infer its overall behaviour and relationship with other spatial phenomena. Therefore, the objective of spatial data analysis is 'to increase our basic understanding of the process, assess the evidence in favour of various hypotheses concerning it, or possibly to predict values in areas where observations have not been made' (20: p. 7).

The dental outcomes of the study were the following: (i) the DMFT index (WHO, 1997); (ii) the SiC Index; the proportions of (iii) children free of caries (DMFT = 0); (iv) with high- (DMFT ≥ 4); (v) rampant- (DMFT ≥ 7) caries experience; (vi) the Gini coefficient for the DMFT distribution; and (vii) the DHII. The SiC Index calculation used an online spreadsheet provided by the WHO Collaborating Centre in Malmö University, Sweden in <http://www.whocollab.od.mah.se/expl/siccalculation.xls>. The assessment of Gini coefficients used a spreadsheet provided by the authors in <http://www.fo.usp.br/arquivos/Gini_calculation_for_caries_distribution.zip>. The DHII calculation used a programme prepared by the Dental Health Services Research Unit of the Dental School, University of Dundee, Scotland, which can be downloaded upon request to Dr Zoann Nugent (z.j.nugent@dundee.ac.uk).

The 1991 census (http://www.ibge.net) provided most of aggregate data characterizing the socioeconomic profile of participating towns. Information about two composite indices were also used, the human development index (21) and the child development index (22), which compile information about several indicators of income, instructional levels, health and access to services. Illiteracy rate refers to subjects older than 14 years old. 'Insufficient income' is a national standard for measuring poverty, which refers to the proportion of population receiving a per capita household income lower than half the Brazilian minimum wage, which broadly corresponds to $2 (US) daily.

Official data (23) retrieved in 1998 supplied quantitative information regarding the local provision of public dental services. 'Dental health practitioner' refers to private dental professionals working in each town, according to information provided by the São Paulo Regional Council of Dentistry. The assessment of the community dental health sector used the number of dentists in the public service, their weekly hours of work and the number of restorative dental treatments and tooth extractions that they performed. All these measurements were scaled as area-level population rates.

The local health authority also provided information on the fluoride status of tap water for participating towns (17). A dummy variable discriminated towns fluoridating water supplies for at least five subsequent years in 1998 from those that did not. We also gathered information as to the proportion of households linked to the water supply network, in order to appraise differential levels of access to fluoride in these towns.

The statistical analysis used the SPSS software. We used ordinary least squares (OLS) regression analysis (24) to evaluate the linear association between aggregate figures of oral health and variables concerning SES indices and dental services. We applied the one-sample Kolmogorov–Smirnov test (19) to evaluate the hypothesis of normal distribution for all dental outcomes and explicative variables included in the study.

Results

Figure 1 indicates the distribution of caries in the state of São Paulo, and shows different measurements of overall caries prevalence and severity. Figure 2 provides indications for the measurement of inequality in the distribution of dental disease, by displaying Lorenz curves for the observed sample, and for a Poisson distribution with the same average DMFT. The rampant-caries proportion and the SiC Index were less likely to be normally distributed at the area level, as indicated by the *P*-values associated with the one-sample Kolmogorov–Smirnov test, respectively, 0.053 and 0.095.

The DMFT, the SiC Index and the proportions of children with high- and rampant-caries experience presented strong linear associations (Pearson *r* near or higher than 0.95). The same observation applies to the DHII, the Gini coefficient and the proportion of caries-free children. These observations involve the perception of variables in each set as interchangeable tools for ecological studies assessing factors influencing, respectively, prevalence levels and

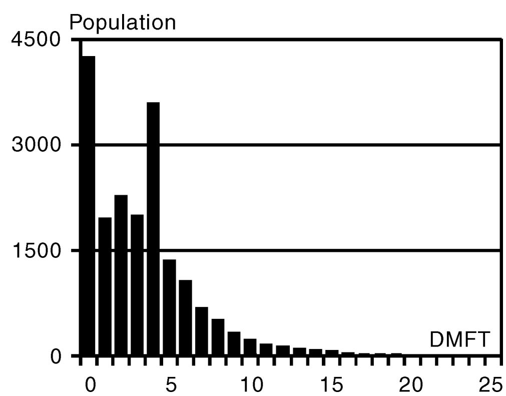

Fig. 1. Distribution of DMFT in 11–12-year-old schoolchildren in São Paulo, Brazil, 1998: DMFT index = 3.28; SiC Index = 6.53; high-caries = 44.2% and rampant-caries proportion = 12.3%. Source: Universidade de São Paulo, 1999 (17).

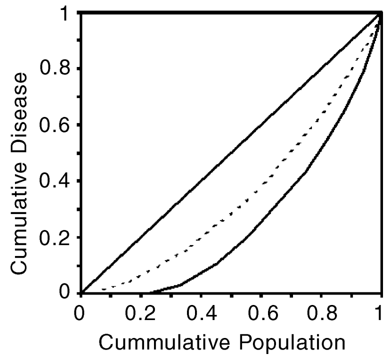

Fig. 2. Lorenz curves for the DMFT distribution (11–12-year-old schoolchildren) in São Paulo, Brazil, 1998: continuous line for the observed sample and dotted line for a Poisson distribution with the same average DMFT. Caries-free proportion = 22.6%; Gini coefficient = 0.491; DHII = 0.267. Source: Universidade de São Paulo, 1999 (17).

inequality in the distribution of dental disease (Table 1).

Being collinear, variables in each set presented similar figures for the correlation coefficient with SES indices and provision of dental services (Table 2). While the DMFT, the SiC Index, and the high- and rampant-caries proportions were rather analogous measurements for considering the area-level association between worse SES indices and higher figures of dental disease, the DHII, the Gini coefficient and the caries-free proportions also performed similarly in the appraisal of the profile of towns with higher inequality in the distribution of dental disease. In general, towns with better living standards had lower levels of caries prevalence concurrent with higher inequality in the distribution of dental disease.

Richer (better socioeconomic standing) towns had both more dental health practitioners and lower prevalence of caries. This pattern was observed for all measures of disease prevalence. Contrariwise, the provision of public dental services correlated positively with caries prevalence, and correlated negatively with inequality in the distribution of dental disease, with all measurements appraised in the present study being similarly effective in indicating these associations (Table 2).

Table 1. Correlation matrix of area-level dental outcomes (11–12-year-old schoolchildren), São Paulo, Brazil, 1998

	Assessing the prevalence and severity of dental disease				Assessing inequality in the distribution of dental disease		
Correlation matrix	DMFT	SiC Index	High caries	Rampant caries	Caries free	Gini	DHII
DMFT	1	+0.965	+0.965	+0.930	−0.888	−0.835	−0.638
SiC Index		1	+0.890	+0.958	−0.776	−0.674	−0.426
High caries			1	+0.841	−0.889	−0.887	−0.712
Rampant caries				1	−0.709	−0.627	−0.393
Caries free					1	+0.960	+0.862
Gini						1	+0.952
DHII							1

Table 2. Pearson *r* coefficient between area-level dental outcomes (11–12-year-old schoolchildren) and variables assessing socioeconomic status and the provision of dental services, São Paulo, Brazil, 1998

	Assessing the prevalence and severity of dental disease				Assessing inequality in the distribution of dental disease		
Indices	DMFT	SiC Index	High caries	Rampant caries	Caries free	Gini	DHII
Socioeconomic status							
Illiteracy rate	+0.384	+0.354	+0.344	+0.313	−0.441	−0.397	−0.344
Income	−0.350	−0.316	−0.333	−0.272	+0.380	+0.350	+0.302
Insufficient income	+0.362	+0.353	+0.325	+0.309	−0.383	−0.325	−0.261
Human development index	−0.366	−0.330	−0.336	−0.295	+0.423	+0.382	+0.341
Child development index	−0.256	−0.248	−0.196	−0.226	+0.268	+0.220	+0.174*
Provision of dental service							
Dental health practitioners	−0.231	−0.229	−0.197	−0.252	+0.186*	+0.160*	+0.112*
Dentists in the public service	+0.309	+0.216	+0.360	+0.196	−0.435	−0.466	−0.473
Weekly hours of dental work	+0.242	+0.179	+0.286	+0.125	−0.331	−0.351	−0.349
Restorative dental treatment	+0.250	+0.153	+0.327	+0.092*	−0.361	−0.410	−0.430
Tooth extraction	+0.282	+0.256	+0.270	+0.195	−0.352	−0.323	−0.283

*$P > 0.05$.

Table 3. Comparative analysis of dental outcomes (11–12-year-old schoolchildren) in towns with and without fluoridated water supply, São Paulo, Brazil, 1998

	52 towns with nonfluoridated water supply	79 towns with fluoridated water supply	*P*-values
Assessing the prevalence and severity of dental disease			
Mean DMFT index	3.89 (3.61–4.17)	2.94 (2.73–3.15)	$P < 0.001$
Mean SiC Index	7.19 (6.79–7.59)	5.81 (5.52–6.11)	$P < 0.001$
Mean high-caries proportion (%)	53.2 (49.1–57.3)	39.6 (36.2–43.1)	$P < 0.001$
Mean rampant-caries proportion (%)	16.2 (13.9–18.6)	9.7 (8.1–11.3)	$P < 0.001$
Assessing inequality in the distribution of dental disease			
Mean caries-free proportion (%)	15.9 (13.3–18.6)	25.1 (22.6–27.7)	$P < 0.001$
Mean Gini coefficient	0.428 (0.407–0.449)	0.492 (0.471–0.512)	$P < 0.001$
Mean DHII	0.199 (0.178–0.220)	0.243 (0.221–0.265)	$P = 0.008$

Table 4. Pearson *r* coefficient between area-level dental outcomes (11–12-year-old schoolchildren) and the frequency of households linked to the water supply network, São Paulo, Brazil, 1998

	52 towns with nonfluoridated water supply	79 towns with fluoridated water supply
Assessing the prevalence and severity of dental disease		
DMFT	−0.277 ($P = 0.084$)	−0.514 ($P < 0.001$)
SiC Index	−0.290 ($P = 0.070$)	−0.487 ($P < 0.001$)
High caries	−0.243 ($P = 0.131$)	−0.472 ($P < 0.001$)
Rampant caries	−0.272 ($P = 0.090$)	−0.439 ($P < 0.001$)
Assessing inequality in the distribution of dental disease		
Caries free	+0.131 ($P = 0.420$)	+0.546 ($P < 0.001$)
Gini	+0.149 ($P = 0.359$)	+0.468 ($P < 0.001$)
DHII	+0.077 ($P = 0.637$)	+0.377 ($P = 0.001$)

These variables were also similarly effective in indicating the supply of fluoridated tap water as an effective resource for reducing levels of caries prevalence and severity, in spite of its concurrent association with increasing levels of inequality in the distribution of dental disease (Table 3). The observation of sound negative correlation coefficients (Pearson *r* ranging from −0.393 to −0.889) between indices of caries prevalence and measurements of inequality in the distribution of the disease (Table 1) also indicates that although related with reduced levels of caries prevalence, recent preventive interventions were associated with an increased inequality in the distribution of dental disease.

These observations are consistent with the comparative analysis of the Pearson correlation coefficient (*r*) between children's dental indices and the area-level frequency of households linked to the water supply network in towns with and without waterborne fluoride. While none of the outcome variables correlated significantly with the proportion of households linked to the water supply network in nonfluoridated towns (i.e. $P > 0.05$), the opposite was observed in towns with fluoride addition (Table 4). We also observed a 35.4% higher average DMFT in fluoridated towns with less than 75% of households linked to the water supply network (DMFT = 3.44), in comparison to the remaining fluoridated towns (DMFT = 2.54).

Discussion

The present study employed extensive information supplied by official agencies of the Brazilian government: a survey of oral health performed by the public health service, a population census, and technical reports on the fluoride status of municipal water supplies and the provision of dental services. Although some variables may be subject to bias and lack information on their validity and reliability, we considered these data as the best information available for the planning of health services.

The ecological fallacy occurs when patterns observed on aggregate data are particularized to individuals. The analyses above are based on whole-town data and must not be fallaciously applied to smaller areas with towns or subsets of populations. Furthermore, the cross-sectional assessment of variables does not allow the appraisal of past levels or trends. In spite of these considerations, there is sufficient evidence supporting spatial data analysis as an effective enhancement for studies aiming at improved interventions in public health (25, 26). These considerations motivated the present study, in which the assessment of correlations between several variables was only a classificatory scheme for describing the ability of dental outcomes in expressing associations with factors affecting the distribution of dental disease.

SES indices

In the present database, towns with better living standards presented lower levels of caries prevalence and severity (Table 2). Although significant at the $P < 0.05$ level, the association between all dental outcomes and SES indices produced modest goodness-of-fit indicators, suggesting that SES indices would not be an effective proxy for caries distribution at the town level. However, besides being a function of the magnitude of Pearson *r*-values, the power of an association (i.e. the probability of correctly rejecting the null hypothesis when it is false) depends on the sample size (27). Thus, Pearson *r*, ranging from 0.3 to 0.5 in an ecological study comprising 131 towns, may be a stronger indicator of association than higher Pearson *r*-values assessed in a lower number of areas.

Towns with better SES indices also presented higher inequality in the distribution of dental caries. Nugent et al. (10) anticipated such a condition, proposing that overall effective health interventions may be more effective in the part of population with less disease. While studying inequalities in service coverage and child health in different Brazilian data sets, Victora et al. (28) observed that the introduction of new medical technologies unequally affects the population, mostly benefiting higher socioeconomic strata. When health initiatives take place before the removal of social gaps and inequalities, they can thus worsen the relative position of the underprivileged in respect of disease prevalence. Causing inequalities in the disease distribution may be an undesirable, but at the same time, unavoidable consequence of preventive interventions associated with the decline of a widespread disease such as caries. However, the importance of monitoring inequalities in the distribution of dental caries relies on the need of preventing what Whitehead (29) called 'health inequities', i.e. inequalities associated with avoidable, unnecessary and unjust differences in health.

Provision of dental services

As private dental treatments demand the payment of a fee, towns with better socioeconomic standing tend to have higher rates of dental health practitioners, despite lower levels of caries prevalence (Table 2). This observation complies with a premise of Hart's 'inverse care law', which states the availability of health care as varying inversely with the need for it in the population served (30).

The provision of public dental services, contrariwise, correlated positively with measures of caries prevalence and severity, which suggests that the health authority tries to implement the access to public dental services in towns with higher levels of need (31, 32). Negative Pearson *r*-values between the provision of public dental services and indices of inequality in the distribution of caries are indicative of a beneficial effect of local community dental services on the reduction of health inequalities (31, 32). Associations between dental outcomes and indices assessing dental services produced similar goodness-of-fit indicators, independent of variables selected for measuring both the prevalence of caries and the inequality of its distribution.

Fluoridated tap water

While confirming tooth decay as a disease associated with social deprivation, Jones et al. (33) verified that the more socially deprived areas benefit more from fluoridation in the British context. According to their study, fluoride addition to the public water supply is an effective initiative for the reduction of caries prevalence concurrent with a reduction in the 'dental health divide'. Notwithstanding, differential levels of access to the network of water supply limit this evaluation, and even such a 'passive' mechanism for the prevention of caries (i.e. non-dependent on dental interventions) has not affected population homogeneously in the Brazilian context.

Besides associating with reduced caries prevalence and severity, fluoride tap water associated with higher figures assessing inequalities in the distribution of the disease, on account of differential levels of access to treated water. Using any of the dental outcomes investigated allowed for similarly assessing this observation (Tables 3 and 4). This observation suggests that there is room for a further reduction of caries levels in São Paulo by expanding the distribution of tap water.

Figures of caries prevalence and severity

Despite being addressed to the part of the population experiencing higher disease levels, the SiC

Index was collinear with the DMFT, which suggests that these variables are interchangeable tools for appraising the association of dental disease prevalence and their correlates in the present data set (Tables 1 and 2). Nishi et al. (34) also observed a strong area-level linear relationship between the DMFT and the SiC Index for data gathered by the Country/Area Profile Programme of the WHO Collaborating Centre in Malmö University, Sweden. These observations, added to the poor performance of the SiC Index in the one-sample Kolmogorov–Smirnov test for the normality of its area-level distribution, reduce some of the expectation in applying this variable as an indication of inequality in the distribution of dental disease in ecological studies. Pitts et al. (35), however, presented a contrasting argument while studying data gathered in 2000–2001 by the British Association for the Study of Community Dentistry (BASCD). According to them, the DMFT alone provides an incomplete picture of the disease in highly skewed distributions, and the SiC Index would supply important additional information about the impact of disease on those most affected.

Also, the proportions of high- and rampant-caries experience were collinear with the DMFT. However, this observation has to be deemed with particular attention because different overall levels of caries prevalence (associated with specific age groups or risk of tooth decay) can modify the present profile of associations. Furthermore, the rampant-caries proportion also presented a poor performance in the one-sample Kolmogorov–Smirnov test for the normality of area-level distribution, and the range of its variation is suggestive of a heteroscedastic (non-homogeneous variance) spatial distribution.

Figures of inequality in the distribution of caries

The strong linear association between the DHII, the Gini coefficient and the proportion of caries-free children involves the perception of these variables as interchangeable tools for assessing inequality in the distribution of dental disease (Tables 1 and 2). As to the selection between the DHII and the Gini coefficient, one should consider restrictions posed to the estimation of the latter when applied to the distribution of an integer-valued variable as the DMFT (10, 36). In the present data set, having or not having at least one tooth affected by caries was an effective indication of inequality in the distribution of dental disease. However, the same observation may not be valid for other studies involving a different age group or subjects affected by different levels of caries risk. This observation accounts for the particular attention demanded while using the proportion of caries-free children in the assessment of inequality in the distribution of dental disease.

The present observation of higher inequality in caries distribution in towns with lower levels of prevalence highlights the importance of the assessment of both dimensions by dental studies. An improved characterization of the skewed distribution of caries experience demands the concurrent estimation of figures of prevalence and inequality, and additional studies should further evaluate these measurements, adding information as to the ability of dental outcomes in reflecting differentials in the profile of services and socioeconomic status. This information may instruct dental programmes aimed at reducing levels of dental disease without reinforcing discrepancies in the experience of caries, a strategy that may contribute to design socially appropriate programmes of oral health promotion.

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