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Do contextual factors have a role in periodontal disease?

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Abstract
Aim: To explore the association between contextual factors and periodontal disease.
Methods: We pooled individual-level data from 20,204 35–44-year-olds and 9,666 65–74-year- olds, who participated in the 3rd National Oral Health Survey in China (2005), with province-level data from different sources. The association of provincial macroeconomic factors [Gross Domestic Product (GDP) per capita and Gini coefficient], health resources (public health expenditure, dentist-to-population ratio and dental-therapist-to-population ratio), demographic composition (proportion of rural population and minority ethnic groups) and tobacco industry (tobacco crops, cigarette production and proportion of smokers) with the numbers of teeth with periodontal pocket depth (PPD) $\geq$ 4 mm and loss of attachment (LOA) $\geq$ 4 mm were assessed in multilevel models, controlling for individual-level demographic, socioeconomic and behavioural factors.
Results: Only the proportion of smokers at province level was associated with the number of teeth with PPD $\geq$ 4 mm and only among senior adults. However, public health expenditure, dentist-to-population ratio and the proportion of minority ethnic groups were associated with the number of teeth with LOA $\geq$ 4 mm in both age groups. GDP per capita was also associated with the number of teeth with LOA $\geq$ 4 mm only among 35–44-year-olds.
Conclusion: Contextual factors may contribute to periodontal disease and help explain geographical inequalities among Chinese adults.

Key words: adults; multilevel analysis; periodontal disease; population characteristics; social environment

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Most studies on risk factors for periodontal disease have focused on the impact of the characteristics of individuals (Genco & Borgnakke 2013, Chapple et al. 2015). There has been comparatively little emphasis on the impact of other factors beyond individuals, such as community or neighbourhood context. The term context is broadly used here to encompass elements of the physical (healthy food outlets, tobacco availability and advertising and safe play areas for children) and social environment (social cohesion or violence) (Diez Roux 2007). The physical and social environments can be hazardous (air/water pollution or crime). They can also limit the choices and resources available to individuals, repeatedly exposing people to stressful conditions, which may in turn exert a direct effect on health (chronic activation of the neuroendocrine system) and an indirect effect through health behaviours as a coping mechanism (Stafford & McCarthy 2005, Macintyre & Ellaway 2009, Diez Roux & Mair 2010). In the case of periodontal diseases, neighbourhood conditions could play a direct role through exposure to environmental tobacco smoke (Akinkugbe et al. 2016). They could also influence behaviours, such as smoking and regular dental check-ups. Furthermore, the deprivation level of a geographical area can influence the health budget and supply of health professionals, and thereby increase or decrease access to care.

Although previous studies have shown geographical inequalities in periodontal disease within (Lopez et al. 2009, Eke et al. 2016) and between countries (Kassebaum et al. 2014), only a few studies have

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looked at contextual determinants as explanations for these differences. The two contextual factors that have received more attention in the literature are area-level deprivation and income inequality. A national study in the US showed that individuals living in poorer neighbourhoods were more likely to have periodontitis, even after controlling for demographic, socioeconomic and behavioural characteristics of participants (Borrell et al. 2006). However, a national study in Scotland subsequently reported no association between area deprivation and periodontitis (Bower et al. 2007). The different results could be explained by the use of multilevel models in the latter study to account for the clustering of individuals within geographical areas. Failing to recognize such a hierarchical structure would underestimate standard errors, leading to an overstatement of statistical significance (Merlo et al. 2005). Similarly, preliminary ecological evidence suggested that more unequal countries have higher rates of periodontitis (Hobdell et al. 2003, Sabbah et al. 2010). A further multilevel analysis of the 2002/03 Brazilian Oral Health Survey among 35–44-year-olds showed that income inequality at municipal level was not associated with periodontal disease (Celeste et al. 2011). Oral epidemiology should pay greater attention to the role of contextual factors in shaping oral health in general and periodontal disease in particular. The association of area composition and environments with periodontal disease highlights the possible role of area-level interventions to improve population oral health and reduce oral health inequalities. To fill this gap in knowledge, a study was undertaken to explore the association between contextual factors and periodontal disease.

Methods

Data source

This cross-sectional study pooled individual- and province-level data from various sources. Individual-level data were used from the 3rd National Oral Health Survey of China (2005) (Qi 2008), which covered the four World Health Organization (WHO) index ages (5-, 12-, 35- to 44- and 65- to 74-year-olds). All 31 provinces of Mainland China participated in the survey, except for Tibet. Participants were selected using multistage stratified cluster sampling. For selection, every province was divided into urban and rural areas; urban areas were classified into three strata by population size, whereas rural areas were classified by Gross Domestic Product (GDP). One city or county was randomly selected from each stratum. Hence, three cities from urban areas and three counties from rural areas were selected from each province. For the next level, three streets or townships were randomly chosen from every city or county respectively. Two residents' committees in these streets (or two villages in townships) were randomly chosen as survey stations. At each survey station, 20 adults and 20 senior adults were recruited randomly from the list of residents provided by each residents' committee (Fig. 1). A target sample of 720 participants in each age group was initially set per province, for a total of 21,600 people nationally. For 35–44-year-olds, 23,538 participated in clinical examinations and 23,522 completed the questionnaire. For 65–74-year-olds, 23,415 were clinically examined and 12,893 completed the questionnaire (only 50% of the senior sample was invited to fill it out).

Variables selection

The number of teeth with periodontal pocket depth (PPD) $\geq$ 4 mm and loss of attachment (LOA) $\geq$ 4 mm were the two outcome measures. Clinical examinations were carried out with participants seated on a chair, and using artificial light, plane mouth mirrors and standard WHO CPI probes. All teeth, excluding third molars, were examined. PPD was assessed at six sites per tooth but only the most severe code was recorded by tooth, according to one of the following categories: 0–3, 4–5, 6+ mm. LOA was also assessed at six sites per tooth but recorded by tooth, according to one of the following categories: 0–3, 4–5, 6–8, 9–11, 12+ mm (WHO, 1997). Unified training sessions were provided to over 200 dentists in Kunming city, Yunnan, before the national survey began. Reliability values were not calculated because of the difficulty of performing such with the large number of examiners.

Data on contextual factors were gathered from different national and international sources matching the survey year as closely as possible. Macroeconomic factors were income inequality and average income. Income inequality was measured using the Gini coefficient, expressed as a percentage, where higher values indicate greater inequality, for the period 1985–1995 (Xu & Zou 2000). More recent income inequality data are not available due to the lack of comprehensive income surveys in China (Xie & Zhou 2014). Average income was measured using the GDP per capita in 2005 expressed in 1000 Yuan (National Bureau of Statistics of China, 2006). Health resources were measured by public health expenditure expressed as a proportion of total government spending on health for 2005 (Fang et al. 2010), and the dentist-to-population and dental-therapist-to-population ratios, expressed per 10 million people, in 2002 (Ministry of Health of China, 2006). Two demographic indicators were also included, namely the proportions of rural residents and minority ethnic groups, extracted from the 5th National Demographic Census in 2000 (National Bureau of Statistics of China, 2001). As the largest tobacco cultivator and cigarette producer in the world (Yang et al. 2015), the strength of the Chinese tobacco industry is likely to be an important factor, influencing the availability of tobacco, social norms about tobacco, smoking rates and exposure to second-hand smoke locally. Two measures relating to the level of tobacco cultivation (in 10 million tons) and cigarette production (in 10 trillion) in 2005 (National Bureau of Statistics of China, 2006), along with the proportion of smokers aged 15–69 years, taken from the 1996 national survey (Chinese Academy of Preventive Medicine, 1997), were also included.

Participants' demographic, socioeconomic and behavioural characteristics were included as covariates to separate contextual from compositional effects (when province-level

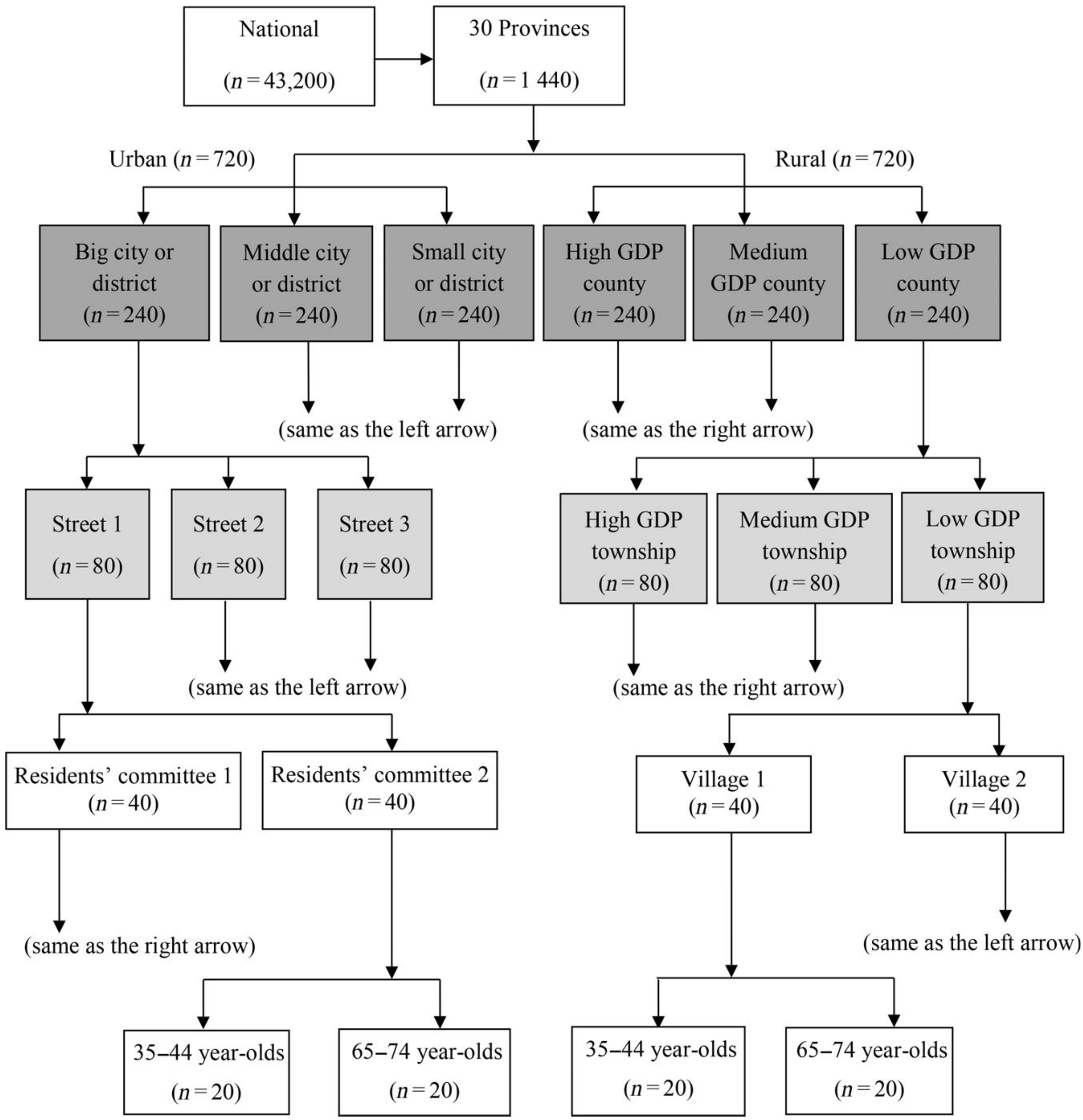

Fig. 1. Sampling process for the 3rd National Oral Health Survey of China (2005). Dark grey boxes represent strata and light grey boxes represent clusters. GDP, Gross Domestic Product.

differences in periodontal measures are explained by the individual composition of the provinces). Demographic factors were sex, age, ethnicity and place of residence (urban or rural). Participants' ethnicity was self-assigned using a list of officially recognized ethnic groups in China, and responses classified as Han or minority ethnic group. Socioeconomic factors were education and household income. Participants reported their total number of years of full-time education, and responses were re-grouped in line with national cut-off points: primary school (0–6 years), junior middle school (7–9 years), senior middle school (10–12 years) and higher education (13+ years). Participants were also asked to provide an estimate of their annual household income with no pre-set categories. Income data were equivalized using the Luxembourg Income Study scale to account for family size. This was achieved by dividing the total household income by the square root of the number of individuals in the family (Buhmann et al. 1988). After equivalization, household income in Chinese Yuan was categorized into five groups: very low (0–4999), low

(5000–9999), medium (10,000–14,999), high (15,000–19,999) and very high (20,000+). Dental behaviours included toothbrushing frequency (not every day, once a day and twice or more a day), last dental visit for any reason (never, within last year, and more than 1 year ago) and smoking status. Participants' smoking status was derived from responses to the questions "how often do you smoke?" and "in the last month, how many cigarettes do you smoke each day?", and classified as never, former, ≤10, 11–20 and >20 cigarettes per day.

Statistical analysis

We first present the composition of the sample of adults and senior adults according to individual and contextual factors. All contextual factors were treated as continuous variables and summarized using mean, standard deviation (SD) and minimum and maximum values.

A two-level random-intercepts and fixed-slopes model structure with individuals nested within provinces was fitted in MLwiN 2.29, using negative binomial regression as the two outcome measures were count variables with over-dispersion. Rate ratios (RR) were thus reported. The number of teeth was used as an offset variable in all models. The numbers of teeth with PPD ≥ 4 mm and LOA ≥ 4 mm were compared by demographic, socioeconomic and behavioural characteristics of individuals in crude negative binomial regression models.

Our modelling strategy was first to estimate empty models (without any covariates) to evaluate the amount of unexplained variance in the numbers of teeth with PPD ≥ 4 mm and LOA ≥ 4 mm at province and individual levels, using the variance partition coefficient (VPC). We then estimated the crude association between every contextual factor and periodontal measures (labelled as Model 1), and gradually adjusted them for individual-level factors (Model 2) and other province-level factors (Model 3). The reason for this strategy was to evaluate compositional and contextual effects when controlling for individual- and province-level confounders respectively. Model 3 also allowed assessment of the relative contribution of contextual factors to explaining variations in periodontal measures. All analyses were conducted using the unweighted sample as the level-2 weights, needed to compensate for the unequal probability of selection of level-2 units (Rabe-Hesketh & Skrondal 2006, Cai 2013), were not available with survey files. Non-weighted analyses were appropriate as our focus was on tests of association rather than deriving nationally representative estimates. More importantly, minimal differences have been observed in estimates and standard errors from weighted and unweighted multilevel regression (Carle 2009).

Results

A total of 20,204 35–44-year-olds (86%), and 9,666 65–74-year-olds (75%), had complete data in all relevant variables and were included in this analysis. The mean number of participants per province was 673 (range: 519–789) among 35–44-year-olds and 322 (range: 216–708) among 65–74-year-olds. The characteristics of the two study samples are shown in Table 1. There were no demographic, socioeconomic or behavioural differences between the study sample and those excluded due to missing data, except for place of residence among 65–74-year-olds (i.e. urban residents were slightly overrepresented in the study sample). The mean numbers of teeth with PPD ≥ 4 mm and LOA ≥ 4 mm were 2.34 (SD: 4.95, 95% confidence interval: 2.28–2.41) and 2.04 (SD: 3.87, 95% CI: 1.98–2.09) in adults and 2.67 (SD: 4.42, 95% CI: 2.58–2.75) and 4.95 (SD: 5.04, 95% CI: 4.84–5.05) in senior adults respectively. Significant differences in the numbers of teeth with PPD ≥ 4 mm and LOA ≥ 4 mm were found by almost all demographic, socioeconomic and behavioural factors (Table 2).

The VPC from the empty models showed that between 3.3% and 4.8% of the variation in the numbers of teeth with PPD ≥ 4 mm and LOA ≥ 4 mm occurred at province level. Tables 3 and 4 show the individual- and contextual-level factors associated with periodontal measures in Chinese adults and senior adults respectively. Only one contextual factor, the proportion of smokers, was associated with the number of teeth with PPD ≥ 4 mm in the adjusted model and this was only among senior adults. A 1-point increase in the proportion of smokers was associated with a 4% increase in the mean number of teeth with PPD ≥ 4 mm. On the other hand, three contextual factors (public health expenditure, dentist-to-population ratio and proportion of minority groups) were significantly associated with the number of teeth with LOA ≥ 4 mm among adults and senior adults. In both age groups, provinces with more public health expenditure had significantly more teeth with LOA ≥ 4 mm, whereas provinces with more dentists per population and higher proportion of minority ethnic groups had significantly fewer teeth with LOA ≥ 4 mm. GDP per capita was also positively associated with the number of teeth with LOA ≥ 4 mm, but only among adults.

Sensitivity analyses using higher thresholds (6 mm) for PPD and LOA were carried out to minimize measurement error in periodontal examinations and the number of false positives. These new analyses confirmed that GDP per capita, dentist-to-population ratio and the proportion of smokers at province level were associated with periodontal measures after adjustments. However, public health expenditure and the proportion of minority ethnic groups were no longer significantly associated with periodontal measures.

Discussion

This study shows that contextual factors may contribute to periodontal disease and help explain geographical inequalities in periodontal disease. Provincial average income, dentist-to-population ratio and the proportion of smokers (and to a lesser extent public health expenditure and the proportion of minority ethnic groups) were associated with periodontal disease over and above the effects of established risk factors such as demographic characteristics, socioeconomic circumstances and behavioural factors.

Some limitations of this study need to be addressed. First, we used

Table 1. Characteristics of the sample of Chinese adults and senior adults

Level 1: Individual	35–44-year-olds	65–74-year-olds
Sex, *n*[a] (%)		
Men	9886 (48.9)	5027 (52.0)
Women	10,318 (51.1)	4639 (48.0)
Ethnicity, *n*[a] (%)		
Han	18,035 (89.3)	8747 (90.5)
Minority ethnic groups	2169 (10.7)	919 (9.5)
Place of residence, *n*[a] (%)		
Rural	9965 (49.3)	4487 (46.4)
Urban	10,239 (50.7)	5179 (53.6)
Education level, *n*[a] (%)		
Up to primary school	5120 (25.3)	6666 (69.0)
Junior middle school	7577 (37.5)	1554 (16.1)
Senior middle school	4895 (24.2)	886 (9.2)
Higher education	2612 12.9)	560 (5.8)
Equivalized income, *n*[a] (%)		
Very low	8220 (40.7)	4937 (51.1)
Low	5632 (27.9)	2267 (23.5)
Medium	3289 (16.3)	1193 (12.3)
High	1246 (6.2)	523 (5.4)
Very high	1817 (9.0)	746 (7.7)
Toothbrushing frequency, *n*[a] (%)		
Less often than daily	2146 (10.6)	2179 (22.5)
Once a day	11,107 (55.0)	4899 (50.7)
Twice a day or more	6951 (34.4)	2588 (26.8)
Last dental visit, *n*[a] (%)		
Never	9156 (45.3)	2779 (28.7)
Within last year	3293 (16.3)	1981 (20.5)
Over 1 year ago	7755 (38.4)	4906 (50.8)
Smoking status, *n*[a] (%)		
Never smoker	12,774 (63.2)	5782 (59.8)
Former smoker	718 (3.6)	1184 (12.2)
≤10 cigarettes/day	1813 (9.0)	1145 (11.8)
11–20 cigarettes/day	2957 (14.6)	1102 (11.4)
20+ cigarettes/day	1942 (9.6)	453 (4.7)
Mean number of teeth with periodontal pocket depth ≥4 mm (SD)	2.21 (4.77)	2.45 (4.15)
Mean number of teeth with loss of attachment ≥4 mm (SD)	2.07 (3.90)	5.28 (5.28)
Mean number of teeth (SD)	27.06 (2.04)	20.82 (7.01)
Level 2: Province (*n* = 30)	**Mean (SD)**	**Range**
Gini coefficient, %	20.80 (2.30)	17.31–27.89
Gross Domestic Product per capita, 1000 Yuan	16.44 (11.05)	5.05–51.47
Public health expenditure, %	4.09 (0.86)	2.80–6.20
Dentist-to-population ratio[b]	4.15 (2.80)	1.31–14.56
Dental-therapist-to-population ratio[b]	1.01 (0.34)	0.44–1.69
Rural population, %	59.94 (16.49)	11.69–76.62
Minority ethnic groups, %	12.43 (16.24)	0.31–59.43
Cigarette production, 10 trillion	6.46 (6.28)	0.00–31.57
Tobacco crops, 10,000 tons	8.95 (16.02)	0.00–79.10
Smokers, %	38.04 (4.68)	28.99–50.45

[a]All counts are unweighted.
[b]Dentist-to-population and dental-therapist-to-population ratios are expressed per 10 million population.

data from a relatively old survey. Despite being conducted in 2005, the 3rd National Oral Health Survey still remains the latest oral health survey available and the contemporary reference in China. No other Chinese survey provides comprehensive oral health data at province level. Second, although six periodontal sites were inspected in every tooth, only one code was recorded per tooth. Partial-mouth assessments maximize the number of people examined in the time available and encourage subjects to comply with the study protocol, but they underestimate the prevalence and severity of periodontal disease (Susin et al. 2005, Holtfreter et al. 2015). Third, examiners were trained before data collection, but examiner reliability was not assessed. This is not a unique characteristic of this survey, but rather a standard feature across national epidemiological surveys (Karimalakuzhiyil Alikutty & Bernabe 2016), reflecting the difficulty to assess reliability when a large number of examiners is involved. That said, we found similar findings in sensitivity analyses using higher thresholds in PPD and LOA to minimize measurement error and false positives. We also found well-known risk factors of periodontal disease (smoking, toothbrushing, education and income) to be associated with our periodontal measures, suggesting that measurement error in periodontal examinations did not seriously affect the results. Fourth, although we tried to match the ecological data as close as possible to 2005, we had to go back 10–15 years for some indicators (income inequality and smoking rates). This should not be a big concern because contextual effects do not act instantaneously but require some time to develop (Diez Roux 2007). Fifth, misclassification of exposure may have occurred if some participants moved between provinces between the assessment of contextual factors and the oral health survey. Interestingly, there is evidence that contextual factors were more strongly related to health measures when analysis was restricted to individuals living in their state of birth (persistent exposure group) compared with the complete sample (Gadalla & Fuller-Thomson 2008). This means that our estimates of the association between contextual factors and periodontal disease may be somewhat conservative.

GDP per capita, dentist-to-population ratio and the proportion of smokers were associated with periodontal disease. Adults in more affluent provinces had more teeth with LOA. Modernization, economic development and increased wealth in China have been accompanied by a shift from diets rich in fibre and staples to diets high in fats and sugars (Popkin 2014). Fibre and whole-grain diets are associated with lower risk of periodontal disease (Merchant et al. 2006, Schwartz et al. 2012). In addition, economic

Table 2. Numbers of teeth with periodontal pocket depth (PPD) ≥ 4 mm and loss of attachment (LOA) ≥ 4 mm, by individual-level characteristics of Chinese adults and senior adults

	35–44-year-olds (n = 20,204)		65–74-year-olds (n = 9666)	
	PPD (95% CI)	LOA (95% CI)	PPD (95% CI)	LOA (95% CI)
Sex				
Men	3.04 (2.93–3.15)	2.48 (2.40–2.57)	3.05 (2.92–3.18)	5.67 (5.52–5.82)
Women	1.68 (1.60–1.76)	2.11 (2.05–2.17)	2.25 (2.14–2.37)	4.16 (4.03–4.29)
p value[a]	<0.001	<0.001	<0.001	<0.001
Ethnicity				
Han	2.40 (2.33–2.47)	2.11 (2.05–2.17)	2.73 (2.64–2.82)	5.04 (4.93–5.14)
Minority ethnic groups	1.87 (1.69–2.05)	1.44 (1.31–1.57)	2.06 (1.82–2.29)	4.06 (3.77–4.35)
p value	<0.001	0.641	<0.001	0.169
Place of residence				
Rural	2.49 (2.39–2.59)	2.19 (2.11–2.27)	2.66 (2.53–2.79)	5.10 (4.95–5.25)
Urban	2.20 (2.11–2.30)	1.89 (1.82–1.96)	2.67 (2.55–2.79)	4.81 (4.67–4.94)
p value	<0.001	<0.001	0.007	<0.001
Education level				
Up to primary school	2.45 (2.31–2.59)	2.20 (2.09–2.31)	2.60 (2.49–2.70)	4.95 (4.84–5.07)
Junior middle school	2.58 (2.46–2.70)	2.17 (2.07–2.26)	2.97 (2.73–3.21)	4.82 (4.57–5.07)
Senior middle school	2.15 (2.02–2.29)	1.97 (1.87–2.08)	2.63 (2.34–2.91)	5.10 (4.74–5.46)
Higher education	1.80 (1.64–1.96)	1.46 (1.34–1.59)	2.71 (2.34–3.08)	4.93 (4.50–5.36)
p value	0.017	<0.001	0.433	0.004
Equivalized income				
Very low	2.77 (2.65–2.89)	2.12 (2.03–2.20)	2.69 (2.56–2.81)	4.91 (4.77–5.04)
Low	2.26 (2.13–2.38)	1.97 (1.87–2.07)	2.61 (2.44–2.79)	4.62 (4.42–4.82)
Medium	2.06 (1.90–2.21)	1.88 (1.75–2.01)	2.56 (2.31–2.80)	5.24 (4.93–5.55)
High	1.69 (1.48–1.91)	1.89 (1.68–2.10)	3.03 (2.61–3.45)	5.29 (4.85–5.74)
Very high	1.63 (1.45–1.81)	2.27 (2.07–2.46)	2.58 (2.27–2.89)	5.47 (5.08–5.86)
p value	<0.001	<0.001	0.736	<0.001
Toothbrushing frequency				
Less often than daily	3.09 (2.84–3.34)	2.11 (1.95–2.26)	3.00 (2.80–3.20)	4.62 (4.43–4.82)
Once a day	2.50 (2.41–2.60)	2.16 (2.08–2.23)	2.67 (2.54–2.79)	5.13 (4.99–5.28)
Twice a day or more	1.86 (1.76–1.96)	1.83 (1.74–1.91)	2.38 (2.23–2.54)	4.86 (4.67–5.06)
p value	<0.001	<0.001	<0.001	0.004
Last dental visit				
Never	2.44 (2.33–2.54)	1.95 (1.87–2.03)	3.05 (2.87–3.23)	5.46 (5.27–5.66)
Within last year	2.24 (2.08–2.41)	2.13 (2.00–2.27)	2.30 (2.12–2.48)	4.77 (4.55–4.99)
Over 1 year ago	2.28 (2.17–2.38)	2.10 (2.01–2.19)	2.60 (2.48–2.72)	4.72 (4.59–4.86)
p value	0.336	0.001	0.003	<0.001
Smoking status				
Never smoker	1.79 (1.72–1.86)	1.71 (1.65–1.77)	2.26 (2.16–2.37)	4.41 (4.29–4.53)
Former smoker	2.54 (2.17–2.92)	2.51 (2.20–2.83)	2.96 (2.69–3.23)	5.73 (5.42–6.05)
≤10 cigarettes/day	2.97 (2.70–3.23)	2.23 (2.05–2.42)	3.45 (3.15–3.75)	5.49 (5.18–5.80)
11–20 cigarettes/day	3.42 (3.21–3.63)	2.68 (2.52–2.83)	3.33 (3.05–3.62)	6.10 (5.78–6.42)
20+ cigarettes/day	3.70 (3.42–3.97)	2.86 (2.65–3.06)	3.44 (3.00–3.87)	5.51 (5.01–6.00)
p value	<0.001	<0.001	<0.001	<0.001

[a]p values were derived from crude multilevel negative binomial regression models with the number of teeth used as an offset variable.

development could also result in more stressful work environments, with longer working hours and more demanding jobs. The latter argument would explain why the association was only found among adults, since most senior adults would probably be retired from work. Having more dentists working locally could make access to dental and periodontal care easier, which may subsequently lead to better periodontal status. On the other hand, the proportion of smokers may be a proxy for exposure to second-hand smoke, which has been associated with periodontal disease (Akinkugbe et al. 2016). The fact that the association was only found among senior adults suggests a long-term exposure to environmental tobacco smoking.

Public health expenditure and the proportion of minority ethnic groups were also associated with periodontal disease, although these results were not confirmed in sensitivity analysis. The estimate for public health expenditure was counterintuitive since residents of provinces with higher public spending on health had more teeth with LOA. It is possible that public investment in health leads to increased life expectancy, and subsequently more periodontal disease, a condition that becomes more prevalent with age (Kassebaum et al. 2014). However, this would not explain the association found among 35–44-year-olds. Another explanation could be that public investment in health care may lead to greater provision of dental care in the form of inter-proximal restorations, which are a risk factor for periodontal disease (Broadbent et al. 2006).

Table 3. Models for the associations of individual- and province-level characteristics with numbers of teeth with periodontal pocket depth (PPD) ≥ 4 mm and loss of attachment (LOA) ≥ 4 mm among 35–44-year-old Chinese adults

Outcome	Contextual factor	Model 1[a] RR[b] (95% CI)	Model 2[a] RR[b] (95% CI)	Model 3[a] RR[b] (95% CI)
PPD	Gini coefficient, %	0.93 (0.83–1.04)	0.92 (0.82–1.02)	0.94 (0.83–1.05)
	Gross Domestic Product (GDP) per capita, 1000 Yuan	1.00 (0.98–1.03)	1.01 (0.98–1.03)	1.02 (0.95–1.10)
	Public health expenditure, %	1.00 (0.73–1.36)	1.03 (0.76–1.40)	0.99 (0.72–1.36)
	Dentist-to-population ratio[c]	1.04 (0.94–1.14)	1.05 (0.95–1.15)	1.08 (0.91–1.29)
	Dental-therapist-to-population ratio[c]	1.18 (0.53–2.62)	1.15 (0.52–2.52)	1.15 (0.48–2.78)
	Rural population, %	1.00 (0.98–1.02)	1.00 (0.98–1.01)	1.03 (0.99–1.08)
	Minority ethnic groups, %	0.99 (0.97–1.01)	0.99 (0.97–1.01)	0.99 (0.97–1.00)
	Cigarette production, 10 trillion	0.97 (0.93–1.01)	0.97 (0.94–1.01)	0.95 (0.87–1.05)
	Tobacco crops, 10,000 tons	0.99 (0.97–1.00)	0.99 (0.97–1.00)	1.00 (0.97–1.04)
	Smokers, %	1.03 (0.97–1.09)	1.03 (0.97–1.09)	1.04 (0.99–1.10)
LOA	Gini coefficient, %	0.95 (0.84–1.07)	0.94 (0.83–1.07)	0.97 (0.87–1.08)
	GDP per capita, 1000 Yuan	1.02 (1.00–1.05)*	1.03 (1.00–1.05)*	1.07 (1.01–1.14)*
	Public health expenditure, %	1.19 (0.87–1.63)	1.22 (0.87–1.71)	1.38 (1.04–1.83)*
	Dentist-to-population ratio[c]	1.02 (0.93–1.13)	1.03 (0.93–1.15)	0.81 (0.69–0.95)**
	Dental-therapist-to-population ratio[c]	1.17 (0.51–2.69)	1.26 (0.52–3.07)	1.49 (0.69–3.22)
	Rural population, %	0.99 (0.97–1.01)	0.99 (0.97–1.00)	1.01 (0.98–1.05)
	Minority ethnic groups, %	0.98 (0.97–1.00)*	0.98 (0.97–1.00)*	0.99 (0.97–1.00)*
	Cigarette production, 10 trillion	0.96 (0.92–1.01)	0.97 (0.97–1.01)	0.95 (0.88–1.03)
	Tobacco crops, 10,000 tons	0.98 (0.96–0.99)**	0.98 (0.96–0.99)*	0.99 (0.96–1.02)
	Smokers, %	0.97 (0.92–1.03)	0.97 (0.91–1.03)	1.04 (0.99–1.09)

[a]Model 1 was unadjusted, Model 2 was adjusted for all individual-level factors and Model 3 additionally adjusted for all province-level factors.
[b]Two-level negative binomial regression model was fitted and rate ratios (RR) are reported. The number of teeth was used as an offset variable in all models.
[c]Dentist-to-population and dental-therapist-to-population ratios are expressed per 10 million population.
$*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

Table 4. Models for the associations of individual- and province-level characteristics with numbers of teeth with periodontal pocket depth (PPD) ≥ 4 mm and loss of attachment (LOA) ≥ 4 mm among 65-74-year-old Chinese adults

Outcome	Contextual factor	Model 1[a] RR[b] (95% CI)	Model 2[a] RR[b] (95% CI)	Model 3[a] RR[b] (95% CI)
PPD	Gini coefficient, %	0.94 (0.86–1.02)	0.94 (0.86–1.02)	0.95 (0.87–1.03)
	Gross Domestic Product (GDP) per capita, 1000 Yuan	1.01 (0.99–1.02)	1.01 (0.99–1.02)	1.02 (0.97–1.07)
	Public health expenditure, %	0.92 (0.73–1.15)	0.93 (0.74–1.17)	0.85 (0.68–1.07)
	Dentist-to-population ratio[c]	1.05 (0.98–1.13)	1.05 (0.98–1.13)	1.07 (0.95–1.21)
	Dental-therapist-to-population ratio[c]	1.35 (0.75–2.43)	1.27 (0.71–2.28)	1.01 (0.55–1.87)
	Rural population, %	1.00 (0.98–1.01)	1.00 (0.98–1.01)	1.02 (0.99–1.06)
	Minority ethnic groups, %	0.99 (0.98–1.00)	0.99 (0.98–1.01)	1.00 (0.98–1.01)
	Cigarette production, 10 trillion	0.96 (0.94–0.99)**	0.96 (0.94–0.99)*	0.95 (0.90–1.01)
	Tobacco crops, 10,000 tons	0.99 (0.97–1.00)*	0.99 (0.98–1.00)*	1.00 (0.98–1.03)
	Smokers, %	1.03 (0.99–1.07)	1.03 (0.99–1.07)	1.04 (1.00–1.08)*
LOA	Gini coefficient, %	0.96 (0.89–1.03)	0.96 (0.88–1.03)	0.98 (0.92–1.05)
	GDP per capita, 1000 Yuan	1.01 (1.00–1.03)	1.02 (1.00–1.03)	1.04 (1.00–1.08)
	Public health expenditure, %	1.11 (0.90–1.35)	1.11 (0.90–1.36)	1.25 (1.04–1.49)*
	Dentist-to-population ratio[c]	1.00 (0.94–1.07)	1.01 (0.94–1.07)	0.86 (0.78–0.95)**
	Dental-therapist-to-population ratio[c]	1.00 (0.59–1.69)	1.02 (0.60–1.74)	1.03 (0.62–1.70)
	Rural population, %	1.00 (0.99–1.00)	0.99 (0.98–1.00)	1.01 (0.98–1.03)
	Minority ethnic groups, %	0.99 (0.98–1.00)*	0.99 (0.98–1.00)*	0.99 (0.98–1.00)**
	Cigarette production, 10 trillion	0.98 (0.95–1.01)	0.98 (0.95–1.01)	0.98 (0.93–1.04)
	Tobacco crops, 10,000 tons	0.98 (0.97–0.99)**	0.98 (0.97–0.99)**	0.98 (0.96–1.00)
	Smokers, %	0.98 (0.94–1.02)	0.98 (0.98–0.92)	1.02 (0.99–1.06)

[a]Model 1 was unadjusted, Model 2 was adjusted for all individual-level factors and Model 3 additionally adjusted for all province-level factors.
[b]Two-level negative binomial regression model was fitted and rate ratios (RR) are reported. The number of teeth was used as an offset variable in all models.
[c]Dentist-to-population and dental-therapist-to-population ratios are expressed per 10 million population.
$*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

Moreover, individuals in provinces with larger minority ethnic groups also had fewer teeth with LOA, in spite of the fact that there were no differences in LOA between ethnic groups. Having more people from the same ethnic background within the living area may generate greater cohesiveness, trust and reciprocity; attributes of a community that are related to health (Murayama et al. 2012). Contrarily, minority ethnic groups in less diverse areas may experience discrimination and marginalization, leading to psychosocial stress and poor health (Diez Roux & Mair 2010).

Contrary to our hypothesis, tobacco crops and cigarette production were not associated with periodontal disease. This might be attributed to the strict regulation on cigarette prices and accessibility imposed by the Chinese government across regions. Income inequality was not associated with periodontal disease either. Our Gini values for all provinces were below the 0.30 threshold effect for income inequality, above which an association with health is more likely to be found (Kondo et al. 2012). Levels of income inequality in China started to increase dramatically in the 1990s (Xie & Zhou 2014). Therefore, it would be interesting to corroborate this finding when more recent Gini data at province level becomes available.

This study shows that the context matters for periodontal health. Our finding highlights the unique contribution of contextual factors and the role of multilevel models in separating contextual from compositional effects (the simple aggregation of individual-level factors). Policies and interventions for prevention of periodontal disease may benefit from taking into consideration the environment in which people live and work. Further research must explore the probable mechanisms by which the physical and social environments may affect periodontal status in order to inform appropriate policy action.

In conclusion, this study provides evidence on the importance of contextual factors to periodontal disease and to explain geographical inequalities. Further research is needed on the underlying pathways linking the environment to periodontal disease.

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Clinical Relevance

Scientific rationale for the study: Most research on risk factors for periodontal disease has focused on the impact of individual characteristics. The physical and social environment where people live and work has been largely overlooked.

Principal findings: Some, but not all, contextual factors were associated with periodontal disease, independent of well-known risk factors acting at individual level.

Practical implications: This study shows that the context matters for periodontal health. We may improve our understanding of periodontal disease with a broader look at the features of the environment that shape people's behaviours and oral health.