Community Dental Health (2018) **35,** 217–222
Received 23 April 2018; Accepted 15 July 2018

doi:10.1922/CDH_4383Weston-Price06

A multi-variable analysis of four factors affecting caries levels among five-year-old children; deprivation, ethnicity, exposure to fluoridated water and geographic region

Weston-Price S[1], Copley V[2], Smith H[3] and Davies GM[4]

[1]Speciality Registrar in Dental Public Health, Public Health England (London); [2]Principal Analyst, Risk Factors Intelligence, Public Health England; [3]Head of Health Intelligence – National Child and Maternal Health Intelligence Network, Public Health England; [4]Consultant in Dental Public Health, Public Health England

Objective: To assess the role of factors posited to affect population caries levels across England. ***Basic research design:*** Multivariable regression analysis assessing four potential determinants of caries severity and prevalence: deprivation, exposure to fluoridated water, ethnicity and geographic region ***Participants:*** Random sample of 121,875 five-year-old children in England in the 2014/15 academic year. ***Main outcome measures:*** Decayed, missing and filled teeth, with decay measured at the dentinal level, ($d_3$mft), presented as prevalence (dmft>0) and extent of decay among children who have any ($d_3$mft if $d_3$mft>0). ***Independent variables:*** Parental reported ethnicity from school records, index of multiple deprivation (IMD) scores, region and exposure to water fluoridation calculated utilising home postcodes. ***Results:*** The data support wider literature displaying associations between caries and deprivation across a social gradient. The important, new findings are deprivation, some ethnic groups and lack of exposure to water fluoridation are all associated with increased prevalence and severity of caries when considered together and independently. New evidence supports the impact of water fluoridation on health inequalities in that the greatest impact of exposure to fluoridated water was seen in the most deprived children and those from an Asian / Asian British ethnic group. ***Conclusions:*** Five-year-old children who were from the most deprived areas, not exposed to fluoridated water, of an Eastern European ethnic group and living in the North West demonstrated the highest prevalence and severity of caries in the survey under scrutiny. This is of public health importance, providing evidence for population groups to target with health improvement activities.

Keywords: caries, children, deprivation, ethnicity, water fluoridation,

Introduction

Even though there have been significant improvements in children's oral health over the past five decades, almost a quarter (24.8%) of five year olds in England still have experience of caries in their primary dentition. Dental caries causes pain, discomfort, sleepless nights and time off school with far reaching impacts at the family level, including parents needing to take time from work to care for children with toothache. Dental decay is the most common reason why children aged five to nine are admitted to hospital, for dental extraction, usually under a general anaesthetic, costing the NHS in the region of £30 million a year.

The proportion of children affected by caries varies at a regional and national level (PHE, 2016b) and is subject to large inequalities (Petersen and Kwan, 2011). Research into the role of wider determinants, which shape inequalities, aims to inform interventions which may address these differences at a population level (Watt, 2007). There is a large body of work demonstrating oral health inequalities exist across the social gradient (Sabbah *et al*., 2007) with those from the most deprived parts of society experiencing the greatest burden of oral disease (Watt and Sheiham, 1999). However, there has long been debate over which other factors may also play a role. National surveys examining caries in five-year-old children in England have noted correlations between decay experience and deprivation, and variations across regions, local authorities, and more recently across ethnic groups (PHE, 2016b). Water fluoridation has also been documented as being effective at reducing levels of tooth decay among children (Iheozor-Ejiofor *et al*., 2015) and, although there has been suggestion that water fluoridation may lead to a decrease in dmft across the social classes (McDonagh *et al*., 2000), there has been insufficient information to determine the role this measure plays in reducing inequalities.

This study aims to assess the role of four factors which have been posited to affect population caries levels: deprivation, exposure to fluoridated water, region and ethnicity, utilising a representative national sample of 5 year old children across England, employing multivariable regression to assess their individual contribution to oral health inequalities.

Method

As part of Public Health England's National Dental Epidemiology Programme (NDEP), standardised examinations of random samples of five-year-old children were undertaken in the 2014/15 academic year, following a national protocol

Correspondence to: Dr Gill Davies, Consultant in Dental Public Health, Public Health England. Email: gill.davies@phe.gov.uk

(PHE, 2014). The aim was to measure the prevalence and severity of obvious dental caries among five-year-old children within each local government area in England, using caries diagnostic criteria and examination techniques based on those agreed by the British Association for the Study of Community Dentistry (BASCD). The sampling frame for this survey was children attending mainstream schools who were aged five years at the time of the survey. Data were collected by trained and calibrated examiners who were generally employed by NHS Trusts providing community dental services and who followed the national survey protocol (PHE, 2014). A visual-only examination method was used to assess decayed, missing and filled teeth ($d_3$mft), with decay measured at the dentinal level. The collection of ethnicity data was made compulsory in the 2014/15 survey and was taken from school records which used parents' reporting of family ethnic group when their child started at school. The ethnicity code set used for school census returns reflects categories used in the 2001 national population census. The home postcodes of the volunteer children were used to assign national index of multiple deprivation (IMD) quintiles (Ministry of Housing Communities and Local Government, 2015) and the known exposure to water fluoridation dichotomised into exposed / not exposed. The assistance of the PHE national leads for water fluoridation was sought to inform which areas had received fluoridated water; those children categorised as "exposed" were children living in areas known to have tap water containing fluoride at a level of 0.7 to 1.0 ppm during the five years before the survey compared to those who were not living in such areas categorised as "not exposed".

The analysis used two multivariable regression models to assess the association between caries and the four potential determinants of: deprivation quintile, exposure to fluoridated water, ethnicity and geographic region. Multivariable model 1 investigates the associations between these four factors and the dichotomous outcome of prevalence (dmft>0). Multivariable model 2 incorporates the same potential determinants but takes as its outcome the extent of decay among children who have any decay. Model 2 is therefore fitted on a reduced sample of children with a $d_3$mft score of one or more. This multivariable regression approach means that all potential determinants of the outcome were considered together in the same model producing coefficients for each potential determinant adjusted for the other determinants in the model.

Multivariable model 1 has a binary outcome and was fitted using logistic regression. The count outcome of model 2 is, by construction, truncated at one and was fitted using a truncated negative binomial regression. This latter model was chosen because of the variance present in the dmft count data. The four determinants of interest were included in the models as main effects while two- and three-way interaction terms between ethnicity, deprivation and water fluoridation status were added by forward selection to test for any moderating effects on the outcomes. Interaction terms were only retained in the final models if they were significant at the 5% level and main effects also remained significant. Variables were tested for significance by examining deviance differences between pairs of nested models. All statistical analysis was performed in R (RCoreTeam, 2017). The regression models were fitted using the R packages glm (model 1) and glmmADMB (model 2) (Fournier *et al*., 2012; Skaug *et al*., 2016).

Results

Of 122,022 children surveyed, a sample of 121,875 was available for analysis. Ten records were excluded from analysis due to incomplete observations, while a further 137 in one religious group were excluded as they were drawn entirely from a single local authority, which would limit the generalisability.

Characteristics of the study population are presented in Table 1. The most deprived children, those in IMD national quintile 1, made up 23.2% of the overall sample but represent 33.6% of those in the sample with $d_3$mft>0. Asian and Eastern European children and those living in areas without water fluoridated at a level of >0.7 ppm in the relevant years before the survey were also over-represented in the sample group with decay. Conversely, the least deprived children in IMD national quintile 5 made up 18.3% of the sample but represent only 11.0% of those with $d_3$mft>0.

Higher mean counts of $d_3$mft in those children with decay were seen in children from Asian and Eastern European families. Lower mean counts of $d_3$mft were seen in children living in the least deprived quintiles and in those children who were exposed to fluoridated water (Table 1).

Table 2 gives the odds ratios (OR) estimated by model 1 and the incidence rate ratios (IRR) estimated by model 2. All significant terms are included in this table except for the interaction of ethnicity with deprivation quintile, detail of which is supplied in the online appendix.

Children from the most deprived quintile demonstrated almost three times the odds (OR 3.32, 95% CI 3.13, 3.52) of caries being present in comparison to those from the least deprived quintile (Table 2) with these findings following a social gradient for caries presence and severity. Being exposed to fluoridated water was associated with a reduced odds ratio of caries being present (OR 0.83, 95% CI 0.72,0.95) and this effect increased with increasing deprivation, as indicated by the odds ratios for the water fluoridation and deprivation interaction term which all take values below 1 (Table 2 Model 1). However, only quintile 1 (most deprived) showed an effect of fluoridation that was significantly different from its effect in quintile 5 (least deprived) (Table 2). For example, five year olds in the most deprived quintile who were exposed to optimally fluoridated water had, on average, odds of any decay that are 0.79 those of similarly fluoride exposed children in the least deprived quintile (95% CI 0.69, 0.90). For a child from the most deprived quintile in the reference categories of the other model variables (White, from South East England) the average net beneficial effect of exposure to fluoridated water on presence of decay may be calculated in terms of odds ratios as $OR_{exposed\_to\_fluoride} * OR_{exposed\_to\_fluoride\_and\_most\_deprived\_quintile} = 0.83 * 0.79 = 0.66$ (95% CI 0.60, 0.71). In other words children in the most deprived quintile who were exposed to optimally fluoridated water had, on average, odds of any decay that were 66% of the odds of equivalent children from the most deprived quintile who had not been exposed to optimally fluoridated water.

Table 1. Description of the sample. Total n=121,875

	Overall		*$d_3mft>0$*		*d_3mft if $d_3mft>0$*			
	n	*% of overall sample* [a]	*n*	*% of those with $d_3mft>0$* [a]	*mean*	*25th percentile*	*median*	*75th percentile*
Ethnicity								
White	90,426	74.2	19,953	66.4	3.17	1	2	4
Mixed	5,558	4.6	1,392	4.6	3.29	1	2	5
Asian / Asian British	12,992	10.7	4,798	16.0	4.00	2	3	6
Black / Black British	5,822	4.8	1,253	4.2	3.30	1	3	4
Other Ethnic Group	2,464	2.0	1,132	3.8	4.41	2	4	6
Eastern European	917	0.8	438	1.5	4.65	2	4	6
Arabic / Turkish	264	0.2	119	0.4	4.01	2	3	6
Ethnic group not provided	3,432	2.8	955	3.2	3.43	1	2	5
IMD national quintile								
Most deprived 1	28,326	23.2	10,086	33.6	3.82	2	3	5
2	25,881	21.2	7,284	24.3	3.57	1	3	5
3	23,078	18.9	5,126	17.1	3.18	1	2	4
4	22,294	18.3	4,237	14.1	2.90	1	2	4
Least deprived 5	22,296	18.3	3,307	11.0	2.63	1	2	3
*Exposure to fluoridated water**								
No	106,932	87.7	26,815	89.3	3.45	1	3	5
Yes	14,943	12.3	3,225	10.7	2.92	1	2	4
Region								
East Midlands	9,112	7.5	2,460	8.2	3.28	1	2	4
East of England	16,056	13.2	3,174	10.6	3.20	1	2	4
London	20,863	17.1	5,906	19.7	3.74	2	3	5
North East	2,796	2.3	780	2.6	3.40	1	2	5
North West	10,278	8.4	3,325	11.1	3.78	1	3	5
South East	23,174	19.0	4,873	16.2	3.26	1	2	4
South West	10,610	8.7	2,303	7.7	3.02	1	2	4
West Midlands	17,058	14.0	3,936	13.1	3.06	1	2	4
Yorkshire and The Humber	11,928	9.8	3,283	10.9	3.50	1	3	5

* children living in areas known to have tap water containing fluoride at a level of 0.7 to 1.0 ppm during the five years prior to the survey compared to those who were not living in such areas

[a] percentages may not add to 100 due to rounding

In contrast, the net beneficial effect of exposure to fluoride in a child from the least deprived quintile was, on average, a smaller reduction in odds of 17% compared to the reference unexposed group (OR 0.83, 95% CI 0.75, 0.95). The greater proportionate benefit of water fluoridation in the most deprived quintile compared to the least is illustrated in Figure 1, which shows a bigger gap in probability of any decay between exposure to fluoridated water and non-exposure in the most deprived quintile compared to the least.

Variation in odds of caries prevalence was noted according to ethnicity. When holding all other factors constant five-year-old children from an Eastern European ethnic group had on average, over three times the odds of having caries experience (OR 3.42, 95% CI 1.47, 7.95) than children from a White ethnic group. This compares with Asian/Asian British children who had, on average, odds of caries experience which are more than double those of children from a White ethnic group (OR 2.51, 95% CI 2.15, 2.94).

The fluoride and ethnicity interaction term of model 1 indicates that fluoride had a bigger proportional impact (benefit) on prevalence of caries in the Asian / Asian British ethnic group when compared to those from the reference White ethnic group (OR 0.80, 95% CI 0.71, 0.90).

Finally, there was variation in caries by region with the greatest increased odds of caries experience among five-year-old children from the North East (OR 1.27, 95% CI 1.15, 1.40), North West (OR 1.42, 95% CI 1.34, 1.51), East Midlands (OR 1.31, 95% CI 1.24, 1.39) and Yorkshire (OR 1.17, 95% CI 1.11, 1.24) compared to the South East. Lower odds of any decay were found for East of England and London (in both cases OR 0.92, 95% CI 0.87, 0.98).

The direction of these associations remained with regards to caries severity, in that there was increased caries severity seen in the most deprived (IRR 1.52 95% CI 1.46, 1.58), decreased caries severity in those exposed to fluoridated water (IRR 0.82 95% CI 0.79, 0.85) and variation across ethnic groups with the greatest severity seen in Eastern European ethnic groups (IRR 1.45 95% CI 1.37, 1.54). There was a significant differential effect of water fluoridation on the severity of caries in the Asian/Asian British group when compared to the White reference group, shown by the ethnicity/

Table 2. Odds Ratios (OR) and Incident Rate Ratios (IRR) of the multivariable regression models of any decay (model 1) and extent of decay (model 2)[a]

Variable	*Model 1* $d_3mft > 0$ *(yes/no)*		*Model 2* number of d_3mft *(if* $d_3mft>0$*)*	
	Adjusted OR	*95% CI*	*Adjusted IRR*	*95% CI*
Ethnicity				
White	ref		ref	
Mixed	1.16	0.96, 1.41	1.03	0.99, 1.07
Asian / Asian British	2.51	2.15, 2.94	1.26	1.23, 1.28
Black / Black British	1.52	1.05, 2.21	0.98	0.94, 1.02
Other Ethnic Group	3.22	2.40, 4.32	1.39	1.34, 1.45
Eastern European	3.42	1.47, 7.95	1.45	1.37, 1.54
Arabic / Turkish	1.42	0.16, 12.26	1.21	1.05, 1.39
Ethnic group not provided	1.46	1.16, 1.85	1.03	0.97, 1.09
IMD national quintile				
Most deprived 1	3.32	3.13, 3.52	1.52	1.46, 1.58
2	2.18	2.06, 2.31	1.40	1.35, 1.46
3	1.58	1.49, 1.68	1.26	1.21, 1.31
4	1.34	1.26, 1.42	1.13	1.08, 1.17
Least deprived 5	ref		ref	
Exposure to fluoridated water				
No	ref		ref	
Yes	0.83	0.72, 0.95	0.82	0.79, 0.85
Region				
East Midlands	1.31	1.24, 1.39	0.97	0.93, 1.01
East of England	0.92	0.87, 0.98	0.98	0.94, 1.02
London	0.92	0.87, 0.98	0.98	0.94, 1.02
North East	1.27	1.15, 1.40	1.02	0.96, 1.08
North West	1.42	1.34, 1.51	1.09	1.05, 1.14
South East	ref		ref	
South West	1.07	1.01, 1.14	0.94	0.91, 0.98
West Midlands	1.08	1.02, 1.15	0.96	0.92, 1.00
Yorkshire and The Humber	1.17	1.11, 1.24	1.00	0.96, 1.04
Deprivation and exposure to fluoridated water interaction				
Most deprived 1, exposed	0.79	0.69, 0.90		
2, exposed	0.92	0.79, 1.08		
3, exposed	0.92	0.79, 1.08		
4, exposed	0.89	0.74, 1.06		
Least deprived 5, exposed	ref			
Ethnicity and exposure to fluoridated water interaction				
White, exposed	ref		ref	
Mixed, exposed	1.00	0.82, 1.22	0.91	0.80, 1.05
Asian / Asian British, exposed	0.80	0.71, 0.90	0.90	0.83, 0.97
Black / Black British, exposed	1.02	0.81, 1.29	0.90	0.75, 1.07
Other Ethnic Group, exposed	0.90	0.67, 1.21	1.02	0.87, 1.19
Eastern European, exposed	1.60	1.10, 2.32	1.08	0.93, 1.27
Arabic / Turkish, exposed	0.75	0.43, 1.30	1.17	0.89, 1.54
Ethnic group not provided, exposed	0.84	0.68, 1.05	1.01	0.86, 1.18
Number of observations	121,875		30,040	

[a]Full details of ethnicity and deprivation interaction supplied in online appendix

fluoridation interaction term for this group in model 2 (IRR 0.90, 95% CI 0.83, 0.97). No other ethnic group demonstrated a significant difference to the reference group in terms of an interaction effect of water fluoridation on the severity of decay. The interaction of water fluoridation status and deprivation was not included in the severity of decay model as it caused the main effect of water fluoridation status to become insignificant. The association with region was weaker in the severity model as only the North West had significantly higher severity than the South East (IRR 1.09, 95% CI 1.05,1.14) and South West with significantly lower severity than the South East (IRR 0.94, 95% CI 0.91,0.98).

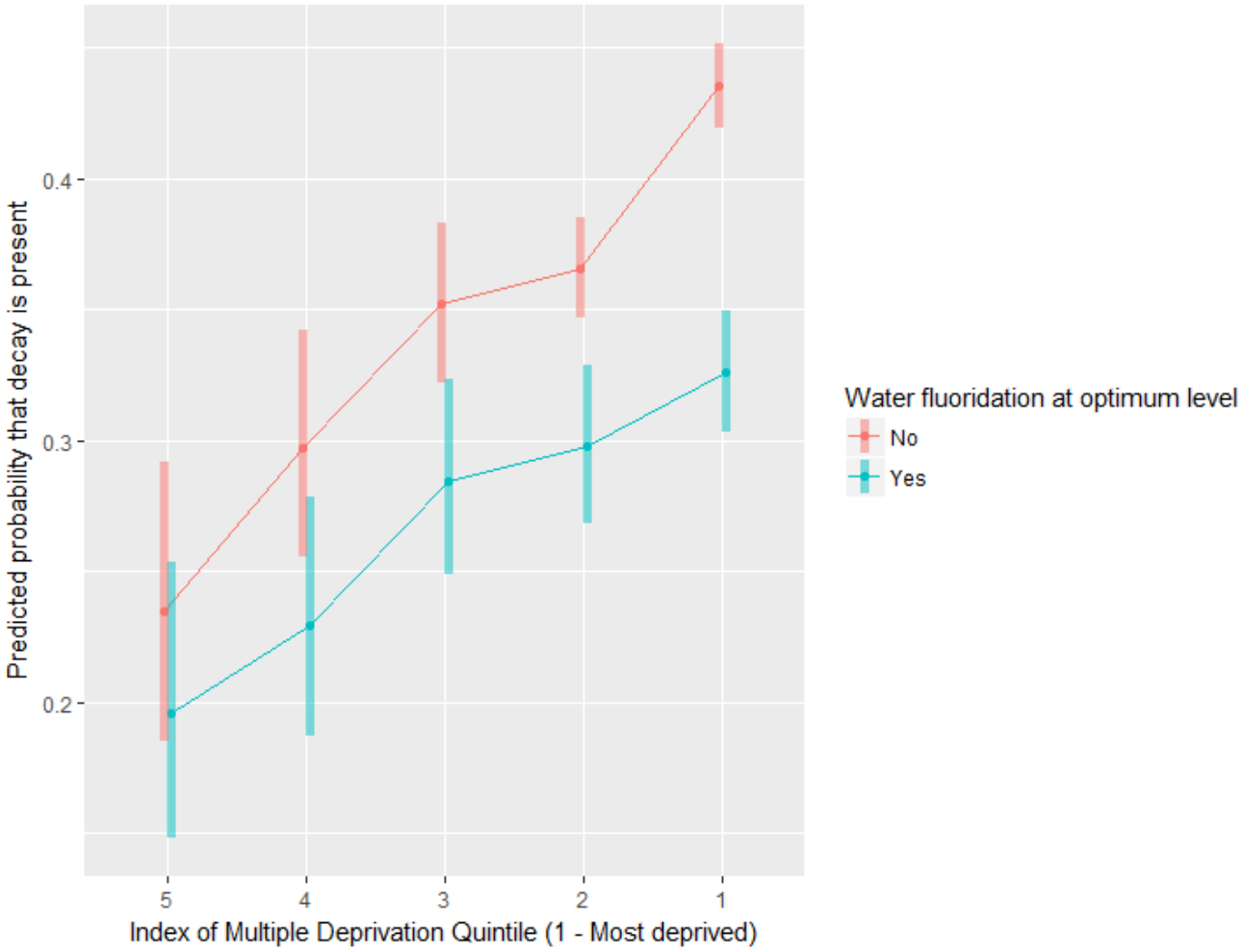

Figure 1. Predicted probability of $d_3mft>0$ by Index of Multiple Deprivation quintile and water fluoridation status, with 95% confidence intervals

Discussion

Caries has long been shown to follow a social gradient (Sabbah *et al*., 2007) and variations in prevalence amongst children have been associated with a complex interplay of multiple factors. Strong evidence from a Cochrane review supports water fluoridation as being effective at reducing levels of tooth decay among children (Iheozor-Ejiofor *et al*., 2015) but the review found insufficient information to determine if it plays a role in reducing inequalities. In addition, the previous York systematic review (McDonagh *et al*., 2000) noted that "the greater the population prevalence of decay at the baseline, the greater the effect of water fluoridation", making it plausible that children from the most deprived quintile at high risk to caries should benefit most from water fluoridation.

This current study reveals a significant association between the prevalence and severity of decay and exposure to fluoridated water, which persists after deprivation, ethnicity and region of residence are accounted for, suggesting that a child with exposure to a fluoridated water supply has, on average, odds of the presence of caries that are 17% lower than those of a similar child without exposure (OR 0.83, 95% CI 0.72, 0.95). Further analysis was conducted to assess the interaction between water fluoridation and deprivation and their joint effect on caries to determine the impact that water fluoridation has on reducing inequalities. Water fluoridation had a bigger proportional impact on the probability of caries prevalence in the more deprived quintiles, compared to the least deprived and that water fluoridation has a bigger proportional impact (benefit) on prevalence of caries in the Asian / Asian British ethnic group when compared to those recorded as from a White British group. This aligns with the findings of the recent Health Monitoring Report (PHE, 2018) and provides strong evidence that water fluoridation has a role in reducing oral health inequalities. It is important to note that there is some evidence in the Health Monitoring Report that sub-optimal fluoride concentrations are associated with lower caries severity (PHE, 2018). In the absence of information on levels of suboptimal fluoridation the current analysis assessed fluoridation conservatively at the optimal threshold (0.7 to 1.0 ppm) therefore it is likely that there is an underestimation of the beneficial effect of water fluoridation in this study and this is an area for future research.

Ethnicity has also been explored as an explanatory factor in UK oral health inequalities with patterns of oral disease seen to vary across ethnic groups both for children (Prendergast *et al*., 1997; Gray *et al*., 2000; Conway *et al.,* 2007; Marcenes *et al*., 2013) and adults (Arora *et al*., 2016). Although it has been suggested that these ethnic variations could be due to deprivation (Marcenes *et al*., 2013) some differences in caries experience between ethnic groups have been seen to be independent of deprivation measures (Prendergast *et al*., 1997; Gray *et al*., 2000; Conway *et al*., 2007). However these studies were conducted at a regional, not a national level. The study described here found that ethnicity was significantly associated with the presence and severity of decay after partial adjustment for deprivation, exposure to fluoridated water and region of residence on a large national data set.

Regional variations in oral disease have been explored, which have suggested a "north/south divide" (Pitts and Palmer, 1994). It has long been debated whether the regional factor was simply a proxy measure for deprivation or in fact independent and thus contributing to oral health inequalities. The important findings in this current study are that these associations remained significant in partially adjusted multivariable regression models. Thus the analysis reported here supports the idea of regional variation in decay over and above that explained by national deprivation quintile. The reasons for this are an avenue for further research. National deprivation quintile may not capture the full experience of deprivation and other measures of deprivation should be explored in future.

Conclusions

The results of the current study demonstrate four chosen variables; deprivation, exposure to fluoridated water, ethnic background and region, have impacts on caries among five-year-olds that are independent of each other and play a role on the severity of caries and not just prevalence. Although these variables have been explored elsewhere in the literature, this study shows, the authors feel for the first time, that the effects are independent of each other. In addition, the results have indicated a significant association between lack of exposure to fluoridated water and caries severity and prevalence in children and new evidence that water fluoridation has a role in reducing oral health inequalities. Thus, five-year-old children who were from the most deprived areas, not exposed to fluoridated water, of an Eastern European ethnic group and living in the North West demonstrated the highest prevalence and severity of caries. With exposure to fluoridated water having the greatest impact on those from the most deprived background and those from an Asian / Asian British ethnic group. The study provides evidence for population groups within which health improvement activities could be targeted to address oral health inequalities.

Acknowledgements

The considerable efforts of the fieldwork teams, regional trainers and epidemiology coordinators who make the national surveys possible are gratefully recognised. The assistance of the PHE national leads for water fluoridation kindly supplied information about the areas which had received fluoridated water in the relevant years is gratefully noted.

References

Arora, G., Mackay, D. F., Conway, D. I., and Pell, J. P. (2016): Ethnic differences in oral health and use of dental services: cross-sectional study using the 2009 Adult Dental Health Survey. *BioMed Central Oral Health* **17**, 1.

Conway, D. I., I. Quarrell, D. R. McCall, H. Gilmour, R. Bedi and L. M. Macpherson (2007): Dental caries in 5-year-old children attending multi-ethnic schools in Greater Glasgow-the impact of ethnic background and levels of deprivation. *Community Dental Health* **24**, 161-165.

Fournier, D., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M., Nielsen, A., and Sibert J. (2012): AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimization Methods and Software,* 233-249.

Gray, M., Morris, A. J., and Davies, J. (2000): The oral health of South Asian five-year-old children in deprived areas of Dudley compared with White children of equal deprivation and fluoridation status. *Community Dental Health* **17**, 243-245.

Iheozor-Ejiofor, Z., Worthington, H. V., Walsh, T., O'Malley, L., Clarkson, J. E., Macey, R., Alam, R., Tugwell, P., Welch, V., and Glenny, A. M. (2015): Water fluoridation for the prevention of dental caries. *Cochrane Database of Systematic Reviews*, Cd010856.

Marcenes, W., Muirhead, V. E., Murray, S., Redshaw, P., Bennett, U., and Wright, D. (2013): Ethnic disparities in the oral health of three- to four-year-old children in East London. *British Dental Journal* **215**, E4.

McDonagh, M. S., Whiting, P. F., Wilson, P. M., Sutton, A. J., Chestnutt, I., Cooper, J., Misso, K., Bradley, M., Treasure, E., and Kleijnen, J. (2000): Systematic review of water fluoridation *British Medical Journal* **321**, 855-859.

Ministry of Housing Communities and Local Government (2015): English indices of deprivation 2015. From www.gov.uk/government/statistics/english-indices-of-deprivation-2015,

Petersen, P. E., Kwan, S. (2011): Equity, social determinants and public health programmes--the case of oral health. *Community Dentistry Oral Epidemiology* **39**, 481-487.

PHE (2014): Dental Public Health epidemiology programme: Oral health survey of five-year-old children 2014-15 National protocol Version 2 Gateway number: 201416 . From http://www.nwph.net/dentalhealth/14_15_5yearold/Protocol_2014_15_5%20yr%20olds%20v2.pdf

PHE (2016a): Hospital episodes for extraction of teeth for children 0-19years 2011-12 to 2015-16. From www.nwph.net/dentalhealth/Extractions.aspx

PHE. (2016b): Dental Public Health epidemiology programme: National Dental Epidemiology Programme for England: oral health survey of five-year-old children 2015. From www.nwph.net/dentalhealth/survey-results%205(14_15).aspx.

PHE (2018): Water Fluoridation Health monitoring report for England 2018. From https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/692754/Water_Fluoridation_Health_monitoring_report_for_England_2018_final.pdf

Pitts, N. B., Palmer, J. D. (1994): The dental caries experience of 5-, 12- and 14-year-old children in Great Britain. Surveys coordinated by the British Association for the Study of Community Dentistry in 1991/92, 1992/3 and 1990-91. *Community Dental Health* **11**, 42-52.

Prendergast, M. J., Beal, J. F., and Williams, S. A. (1997): The relationship between deprivation, ethnicity and dental health in 5-year-old children in Leeds, UK. *Community Dental Health* **14**, 18-21.

RCoreTeam (2017): "R:A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria. From www.R-project.org/

RCS. (2015): The state of children's oral health in England, RCS. From www.rcseng.ac.uk/fds/policy/documents/fds-report-on-the-state-of-childrens-oral-health.

Sabbah, W., Tsakos, G., Chandola, T., Sheiham, A., and Watt, R. G. (2007): Social gradients in oral and general health. *Journal of Dental Research* **86**, 992-996.

Skaug, H., Fournier, D., Bolker, B., Magnusson, A., and Nielsen A (2016): Generalized Linear Mixed Models using 'AD Model Builder'. *R package version 0.8.3.3*.

Watt, R., and Sheiham, A. (1999): Inequalities in oral health: a review of the evidence and recommendations for action. *British Dental Journal* **187**, 6-12.

Watt, R. G. (2007): From victim blaming to upstream action: tackling the social determinants of oral health inequalities. *Community Dental Oral Epidemiology* **35**, 1-11.

Supplementary information

Table S1. Odds Ratios (OR) and Incident Rate Ratios (IRR) of the full multivariable regression models of any decay (model 1) and extent of decay (model 2), including deprivation and ethnicity interaction. Model 2 sample size insufficient to allow deprivation and ethnicity interaction to be modelled.

Variable	**Model 1** dmft > 0 (yes/no)		**Model 2** number of dmft (if any)	
	Adjusted OR	95% CI	Adjusted IRR	95% CI
Ethnicity				
White	ref		ref	
Mixed	1.16	0.96, 1.41	1.03	0.99, 1.07
Asian / Asian British	2.51	2.15, 2.94	1.26	1.23, 1.28
Black / Black British	1.52	1.05, 2.21	0.98	0.94, 1.02
Other Ethnic Group	3.22	2.40, 4.32	1.39	1.34, 1.45
Eastern European	3.42	1.47, 7.95	1.45	1.37, 1.54
Arabic / Turkish	1.42	0.16, 12.26	1.21	1.05, 1.39
Ethnic group not provided	1.46	1.16, 1.85	1.03	0.97, 1.09
IMD national quintile				
Most deprived 1	3.32	3.13, 3.52	1.52	1.46, 1.58
2	2.18	2.06, 2.31	1.40	1.35, 1.46
3	1.58	1.49, 1.68	1.26	1.21, 1.31
4	1.34	1.26, 1.42	1.13	1.08, 1.17
Least deprived 5	ref		ref	
Exposure to fluoridated water				
No	ref		ref	
Yes	0.83	0.72, 0.95	0.82	0.79, 0.85
Region				
East Midlands	1.31	1.24, 1.39	0.97	0.93, 1.01
East of England	0.92	0.87, 0.98	0.98	0.94, 1.02
London	0.92	0.87, 0.98	0.98	0.94, 1.02
North East	1.27	1.15, 1.40	1.02	0.96, 1.08
North West	1.42	1.34, 1.51	1.09	1.05, 1.14
South East	ref		ref	
South West	1.07	1.01, 1.14	0.94	0.91, 0.98
West Midlands	1.08	1.02, 1.15	0.96	0.92, 1.00
Yorkshire and The Humber	1.17	1.11, 1.24	1.00	0.96, 1.04
Deprivation and exposure to fluoridated water interaction				
Most deprived 1, exposed	0.79	0.69, 0.90		
2, exposed	0.92	0.79, 1.08		
3, exposed	0.92	0.79, 1.08		
4, exposed	0.89	0.74, 1.06		
Least deprived 5, exposed	ref			
Ethnicity and exposure to fluoridated water interaction				
White, exposed	ref		ref	
Mixed, exposed	1.00	0.82, 1.22	0.91	0.80, 1.05
Asian / Asian British, exposed	0.80	0.71, 0.90	0.90	0.83, 0.97
Black / Black British, exposed	1.02	0.81, 1.29	0.90	0.75, 1.07
Other Ethnic Group, exposed	0.90	0.67, 1.21	1.02	0.87, 1.19
Eastern European, exposed	1.60	1.10, 2.32	1.08	0.93, 1.27
Arabic / Turkish, exposed	0.75	0.43, 1.30	1.17	0.89, 1.54
Ethnic group not provided, exposed	0.84	0.68, 1.05	1.01	0.86, 1.18

table S1 continued overleaf...

...table S1 continued

Variable	**Model 1** dmft > 0 (yes/no)		**Model 2** number of dmft (if any)	
	Adjusted OR	95% CI	Adjusted IRR	95% CI
White, least deprived 5	refs			
Mixed, most deprived 1	0.79	0.63, 1.01		
Asian / Asian British, most deprived 1	0.61	0.52, 0.72		
Black / Black British, most deprived 1	0.42	0.28, 0.62		
Other Ethnic Group, most deprived 1	0.65	0.48, 0.89		
Eastern European, most deprived 1	0.60	0.25, 1.45		
Arabic / Turkish, most deprived 1	1.60	0.18, 14.09		
Ethnic group not provided, most deprived 1	0.90	0.68, 1.18		
Mixed, 2	0.92	0.73, 1.17		
Asian / Asian British, 2	0.73	0.61, 0.87		
Black / Black British, 2	0.53	0.36, 0.79		
Other Ethnic Group, 2	0.77	0.55, 1.08		
Eastern European, 2	0.85	0.35, 2.06		
Arabic / Turkish, 2	1.77	0.19, 16.20		
Ethnic group not provided, 2	0.72	0.55, 0.95		
Mixed, 3	1.13	0.87, 1.45		
Asian / Asian British, 3	0.86	0.72, 1.03		
Black / Black British, 3	0.65	0.42, 1.00		
Other Ethnic Group, 3	1.17	0.82, 1.67		
Eastern European, 3	0.85	0.33, 2.18		
Arabic / Turkish, 3	4.18	0.41, 43.05		
Ethnic group not provided, 3	0.91	0.68, 1.23		
Mixed, 4	1.17	0.91, 1.51		
Asian / Asian British, 4	0.90	0.74, 1.09		
Black / Black British, 4	0.65	0.41, 1.04		
Other Ethnic Group, 4	1.17	0.79, 1.74		
Eastern European, 4	0.76	0.28, 2.05		
Arabic / Turkish, 4	2.83	0.20, 39.11		
Ethnic group not provided, 4	0.77	0.56, 1.06		
Number of observations	121,875		30,040	