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The effect of water fluoridation and social inequalities on dental caries in 5-year-old children

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Background Many studies have shown that water fluoridation dramatically reduces dental caries, but the effect that water fluoridation has upon reducing dental health inequalities is less clear. The aim of this study is to describe the effect that water fluoridation has upon the association between material deprivation and dental caries experience in 5-year-old children.

Methods It is an ecological descriptive study of dental caries experience using previously obtained data from the British Association for the Study of Community Dentistry's biennial surveys of 5-year-old children. This study examined the following data from seven fluoridated districts and seven comparable non-fluoridated districts in England:
1) dental caries experience using the dmft (decayed, missing, filled teeth) index;
2) the Townsend Deprivation Index of the electoral ward in which the child lived;
3) whether fluoride was present at an optimal concentration in the drinking water or not.

Results A statistically significant interaction was observed between material deprivation (measured by the Townsend Deprivation Index) and water fluoridation ($P <$ 0.001). This means that the social class gradient between material deprivation and dental caries experience is much flatter in fluoridated areas.

Conclusion Water fluoridation reduces dental caries experience more in materially deprived wards than in affluent wards and the introduction of water fluoridation would substantially reduce inequalities in dental health.

Keywords Caries, fluoridation, deprivation

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Although there have been recent improvements in dental health in the United Kingdom there remain widespread variations between and within communities. These geographical inequalities are strongly associated with deprivation and poverty. Changing people's lifestyles in these communities has proved difficult and dental caries is likely to remain a public health concern for the foreseeable future.[1]

It is well known that water fluoridation reduces the prevalence of dental caries in all social classes.[2] However, less certain is the effect that water fluoridation has upon the relationship between material deprivation and dental caries. Some studies have suggested that addition of fluoride to the drinking water reduces the magnitude of the slope of the association between deprivation and dental caries thereby helping to reduce geographical and social inequalities. Few studies have tested this hypothesis statistically.

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Studies of the relationship between fluoridation, social class and dental caries experience in the deciduous teeth of 5-year-old children living in the North East of England[2–5] show that the absolute reduction in dental caries experience due to water fluoridation is greater in children from social class IV and V than in children from social class I and II. Similar results have been reported from the West Midlands[6] and County Durham[7] although socioeconomic group[6] and Townsend Deprivation Index[7] were used in the analysis rather than social class. However, the interaction between water fluoridation and material deprivation was tested in only two of these studies[3,7] and was shown to be statistically significant in both. More recent studies[8,9] also showed a significant interaction between dental caries experience, material deprivation measured by the Jarman Underprivileged Area Score and water fluoridation among 5-year-old children from fluoridated Newcastle and North Tyneside and non-fluoridated Salford and Trafford. However, these studies did not weight the wards for the number of children examined,[8,9] did not state the number of children examined,[8] compared data from different years[9] and used the Jarman Underprivileged Area Score which is a measure of general practitioner's workload and has been criticized as a measure of material deprivation.[10,11]

A study in Australia[12] showed that in 5-year-old children, those from non-fluoridated areas, showed a marked social gradient in dental caries, while those from fluoridated areas showed only minor variations in dental caries experience. In contrast in New Zealand[13] and Finland[14] water fluoridation had a similar effect in all social classes, and the interaction between water fluoridation and social class was not statistically significant.

Studies in the permanent dentition have also shown varying results. Jones *et al.*[8] showed a statistically significant interaction between material deprivation and dental caries experience when the data were analysed at electoral ward level for children living in fluoridated North Tyneside and Newcastle and non-fluoridated Liverpool. However, Ellwood and O'Mullane[15] in North Wales, Treasure and Dever[16] in New Zealand, Slade *et al.* in Australia[12] and Hausen *et al.* in Finland[17] all failed to demonstrate a significant interaction. It was suggested by Ellwood and O'Mullane[15] that interactions are more difficult to demonstrate when caries levels are lower as the absolute reductions in dental caries are smaller.

Many studies[2–6,13–16] used social class/socioeconomic groups which are based on occupation, data which are difficult to collect and which are often incomplete; for example, high-risk groups such as the long-term unemployed and single parents not in employment cannot be classified, with the effect that up to 20% of subjects may be eliminated from the analysis.[18]

In summary, some previous studies have failed to demonstrate significant interactions between water fluoridation and material deprivation, while others have used inappropriate statistical techniques or have been conducted outside the UK. Furthermore, some workers have suggested that any interaction may depend upon the underlying level of disease in the population.

Aim

The aim of this study was to describe the association between material deprivation and dental caries experience in 5-year-old children living in a range of fluoridated and comparable non-fluoridated communities in England, and to determine whether water fluoridation reduced the social inequalities in dental caries experience.

Methods

This ecological study is a descriptive cross-sectional study of dental caries experience in 5-year-old children. Data were collected in 1993–1994 by districts in England as part of the biennial surveys coordinated on behalf of the NHS by the British Association for the Study of Community Dentistry.[19]

Districts were included in this study if they carried out a full population survey of 5-year-old children, so that all electoral wards in a district were represented. Fluoridated districts were included if at least 90% of the population received fluoridated drinking water with a concentration of at least 0.7 mg/l fluoride and the supply of fluoride in the water had been continuous for the previous 5 years. There were 20 other fluoridated districts which were excluded from this study either because less than 90% of the population received a fluoridated water supply (10 districts), the district survey involved a small sample (seven districts), because the water fluoridation scheme had been implemented for less than 5 years (two districts) or data for 5-year-old children were not available (one district). The seven fluoridated districts included were then paired with a comparable non-fluoridated district. Pairing was based on four census indicators of material deprivation: car ownership, unemployment, household overcrowding and those living in rented accommodation, all of which are components of the Townsend Index, a geographical measure of deprivation.[20] An additional variable, the percentage of residents describing themselves as 'non-white', was also included. In order to be considered for pairing, non-fluoridated districts were required to have <0.3 mg/l fluoride concentration in their drinking water for the last 5 years.

Seven fluoridated districts were eligible for comparisons, and paired with seven non-fluoridated districts. The seven pairs are listed in Tables 1 and 2, the pairs being identified by the letters A to G in the tables. For each ward in these 14 districts the mean number of decayed, missing or filled teeth (mean dmft), the number of 5-year-old children in the ward, the Townsend Deprivation Index for the wards, and whether the districts were fluoridated or non-fluoridated were tabulated.

Statistical analysis

For each of the 14 districts, the association between the Townsend Deprivation Index, and the mean caries experience for each ward was tested using both non-weighted and weighted linear regression models. For the weighted model, weightings were based on the number of children in each ward. These models established the slope and intercept of the regression line and the strength of the association (r). The statistical significance of the difference in the slope of the association between deprivation and dental caries for all the wards in the 14 fluoridated and non-fluoridated districts was tested using an interaction term in a multiple linear regression model.[15]

Results

In the seven non-fluoridated districts, a total of 25 216 children were included in 318 wards. In the seven fluoridated districts, a total of 16 663 children were included in 121 wards. The number of subjects examined in each district ranged from 1761 (North Birmingham) to 5473 (Sheffield) with a mean of 2989. The percentage of the eligible population examined in each district ranged from 76% (Liverpool) to 94% (East Birmingham) with a mean of 84%.

Summary data for each district are shown in Tables 1 and 2. The mean Townsend score for wards in the fluoridated districts was 1.3 (standard deviation [SD] 4.1) and for the non-fluoridated was 1.2 (SD 4.2). This difference was not statistically significant ($P = 0.84$, t-test). The mean dmft score for wards in the fluoridated districts was 0.87 (SD 0.83) and for the non-fluoridated 1.8 (SD 1.1). This represents a difference of 52% and was statistically significant ($P < 0.001$). The mean number of subjects in the fluoridated wards was 137.3 (SD 115.5) compared to 79.3 (SD 68.5) in the non-fluoridated wards ($P < 0.001$). The range of number of subjects included in wards used to calculate the mean dmft scores was wide (1–670). There was an association between the number of subjects examined in a ward and the ward Townsend score ($r = 0.43$, $P < 0.001$).

Table 1 Mean number of subjects per ward, decayed, missing and filled teeth (dmft) and Townsend score for districts with fluoridated drinking water

		No. subjects per ward		dmft		Townsend score	
District	**No. wards**	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
A Solihull	17	118.5 (36.3)	71–202	0.7 (0.4)	0.3–1.3	–0.9 (4.3)	(–6.7)–(6.7)
B Bromsgrove & Redditch	28	64.8 (26.2)	21–132	0.6 (0.2)	0.1–1.1	–1.1 (3.2)	(–6.7)–(6.3)
C West Birmingham	8	362.9 (82.3)	210–472	1.3 (0.2)	1.0–1.6	6.2 (4.2)	(–0.4)–(11.4)
D North Birmingham	6	293.5 (77.6)	178–369	0.8 (0.3)	0.4–1.2	2.6 (3.7)	(–3.9)–(7.3)
E North Warwickshire	31	66.2 (34.6)	20–135	0.9 (0.3)	0.3–1.6	–0.2 (2.6)	(–5.4)–(5.1)
F Sandwell	24	142.0 (22.6)	96–182	1.1 (0.3)	0.5–1.7	4.5 (2.5)	(0.3)–(9.9)
G East Birmingham	7	383.1 (157.0)	189–670	1.3 (0.4)	0.9–2.1	5.0 (2.3)	(1.9)–(8.0)

Table 2 Mean number of subjects per ward, decayed, missing and filled teeth (dmft) and Townsend score for districts without fluoridated drinking water

		No. subjects per ward		dmft		Townsend score	
District	**No. wards**	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
A Shropshire	144	30.1 (25.7)	1–106	1.1 (0.7)	0.0–4.0	–0.7 (2.3)	(–6.8)–(5.7)
B Chester	29	62.7 (26.6)	21–121	1.8 (0.8)	0.9–4.4	0.7 (4.3)	(–5.9)–(8.3)
C Liverpool	33	155.5 (76.1)	29–377	2.5 (0.8)	1.1–4.0	6.5 (3.9)	(–1.2)–(13.1)
D Trafford	21	105 (19.5)	68–136	2.0 (0.8)	0.3–3.7	0.0 (3.4)	(–4.3)–(7.5)
E Warrington	23	88.3 (44.3)	26–201	1.7 (0.7)	0.5–3.0	–0.5 (3.9)	(–6.3)–(7.0)
F Sheffield	29	188.7 (57.9)	86–365	2.3 (0.8)	0.9–3.7	3.4 (4.0)	(–4.7)–(9.3)
G St Helens & Knowsley	39	108.3 (50.4)	30–235	3.3 (1.0)	1.3–5.5	4.3 (4.3)	(–3.9)–(12.3)

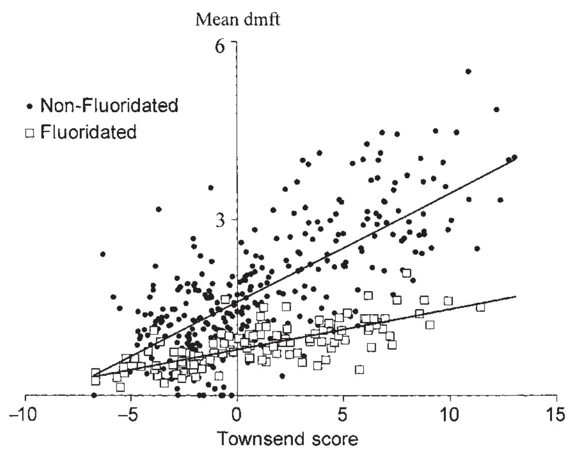

Figure 1 The association between the Townsend score and mean decayed, missing and filled teeth (dmft) for the fluoridated and non-fluoridated wards

The association between the Townsend score and dental caries experience in each of the fluoridated and non-fluoridated districts was modelled separately using both weighted and unweighted least squares regression. It can be seen in Tables 3 and 4 that the β coefficients representing the slope of association between the Townsend score and mean dmft for wards were generally higher in the non-fluoridated (range 0.09–0.19) than fluoridated districts (in which six of the seven districts ranged from 0.04 to 0.08). The only outlying value was the β coefficient for fluoridated East Birmingham (β = 0.17 weighted, β = 0.15 unweighted) where the standard error of the slope was much larger than in the other fluoridated districts. As would be expected the intercept of the regression line, or mean dmft expected at a Townsend score of zero, was much lower in the fluoridated than in the non-fluoridated districts.

Figure 1 shows the association between the Townsend score and mean dmft for the combined fluoridated and non-fluoridated wards. The difference in the slope of the two lines was tested using an interaction term in a multiple linear regression model. For the weighted least squares regression model the β coefficient of the interaction term was 0.09 with a standard error of 0.1 ($P < 0.001$). The overall fit of the model was excellent ($P < 0.001$) and explained approximately 72% (r^2) of the variability of the ward mean dmft scores. The results for the unweighted model were similar with a β coefficient of 0.12 (SE 0.02) for the interaction term. Again the fit of the model was excellent ($P < 0.001$) and explained 61% (r^2) of the variability of the ward mean dmft scores. For both the weighted and unweighted analyses in the fluoridated districts the slope of the association between the Townsend score and mean dmft of wards was approximately half that of the non-fluoridated districts suggesting that geographical inequalities are significantly reduced.

Discussion

The majority of the fluoridated districts in England are in the West Midlands and the North East. However, the districts in the

Table 3 Slope and intercept of regression lines modelling the associations between the Townsend score and mean decayed, missing and filled teeth (dmft) for wards in districts with fluoridated drinking water

	Weighted				Unweighted			
District	β (SE)	Intercept (SE)	r^2	*P*	β (SE)	Intercept (SE)	r^2	*P*
A Solihull	0.08 (0.01)	0.77 (0.03)	0.91	<0.001	0.08 (0.01)	0.77 (0.03)	0.90	<0.001
B Bromsgrove & Redditch	0.05 (0.01)	0.65 (0.04)	0.33	0.001	0.04 (0.01)	0.62 (0.04)	0.33	0.001
C West Birmingham	0.04 (0.02)	1.02 (0.12)	0.50	<0.05	0.04 (0.02)	1.04 (0.11)	0.52	<0.05
D North Birmingham	0.05 (0.03)	0.60 (0.10)	0.49	0.12	0.05 (0.03)	0.62 (0.12)	0.45	0.14
E North Warwickshire	0.05 (0.02)	0.90 (0.05)	0.24	<0.01	0.06 (0.02)	0.91 (0.05)	0.25	<0.01
F Sandwell	0.08 (0.02)	0.68 (0.10)	0.45	<0.001	0.08 (0.02)	0.69 (0.10)	0.44	<0.001
G East Birmingham	0.17 (0.05)	0.44 (0.29)	0.71	0.02	0.15 (0.05)	0.55 (0.26)	0.67	0.02
All districts	0.08 (0.006)	0.77 (0.03)	0.61	<0.001	0.07 (0.006)	0.78 (0.03)	0.55	<0.001

Table 4 Slope and intercept of regression lines modelling the associations between the Townsend score and mean decayed, missing and filled teetch (dmft) for wards in districts without fluoridated drinking water

	Weighted				Unweighted			
District	β (SE)	Intercept (SE)	r^2	*P*	β (SE)	Intercept (SE)	r^2	*P*
A Shropshire	0.09 (0.02)	1.20 (0.04)	0.18	<0.001	0.11 (0.02)	1.21 (0.06)	0.13	<0.001
B Chester	0.12 (0.02)	1.72 (0.10)	0.48	<0.001	0.13 (0.03)	1.71 (0.11)	0.47	<0.001
C Liverpool	0.14 (0.02)	1.71 (0.16)	0.55	<0.001	0.14 (0.03)	1.63 (0.20)	0.48	<0.001
D Trafford	0.19 (0.02)	1.99 (0.08)	0.76	<0.001	0.20 (0.03)	1.95 (0.09)	0.74	<0.001
E Warrington	0.13 (0.03)	1.74 (0.10)	0.53	<0.001	0.13 (0.03)	1.76 (0.11)	0.49	<0.001
F Sheffield	0.17 (0.02)	1.69 (0.09)	0.76	<0.001	0.17 (0.02)	1.68 (0.10)	0.75	<0.001
G St Helens & Knowsley	0.18 (0.02)	2.53 (0.14)	0.58	<0.001	0.17 (0.02)	2.59 (0.14)	0.59	<0.001
All districts	0.17 (0.008)	1.7 (0.04)	0.56	<0.001	0.19 (0.01)	1.58 (0.04)	0.53	<0.001

North East did not fulfil the inclusion criteria for this study as data were unavailable at ward level. All the fluoridated districts which did fulfil the inclusion criteria were included. These fluoridated districts were then paired with the most comparable non-fluoridated district, the latter being situated mainly in the North West. Thus these results are not representative of England as a whole, but of the districts which carried out census surveys.

As with all studies of this type which involve consent for participation, it is possible that caries levels were underestimated as poor school attenders are more likely to come from materially disadvantaged homes.[21] This would tend to underestimate caries levels in the more deprived wards and potentially reduce the magnitude of the interaction between water fluoridation and deprivation. However, the data available for use in this study were of high quality with an average response rate for the 14 districts of 84% which is considered good.[22]

In data analysis the choice of using an unweighted or weighted regression based on the number of subjects in a ward is the source of some controversy[23] and both analyses are shown for this study. Clearly an estimate of a ward mean score for dmft is likely to be more robust when larger numbers of subjects are included. Therefore it would seem prudent to weight the analysis so that wards with many subjects are given greater importance than those with few. The influence of the weighting procedure can be seen in the final regression models that considered the interaction between water fluoridation and Townsend score. The unweighted model explained 61% of the ward variability compared with 72% for the weighted model. However, using weighting procedures can introduce some bias. For these data there was a strong association between the number of subjects examined in a ward and the Townsend score, so that more subjects tended to be examined in the more deprived wards. Thus weighting the model using the number of subjects examined will tend to bias the model in favour of the difference found in the more deprived wards. This can be seen in the β coefficient for the interaction terms which was greater in the unweighted (0.12) than weighted (0.09) analysis. For the unweighted analysis, wards with less than 50 subjects were excluded and the interaction term was still significant ($P < 0.01$).

The interpretation of data from an ecological study of this type must be performed with some caution. Although this study has identified that more deprived wards benefit most from water fluoridation, it has not established that this is true for individuals involved in the study. For example it is possible (but unlikely) that in the deprived wards it is the non-deprived individuals that are benefitting the most and inequalities between individuals are in fact increasing; further studies concentrating on individual subjects within wards are required. Also, because this is an ecological study, a further limitation is the unavailability of data necessary for the control of confounding variables. In this study the confounding variables are:

a) residency—there is a lack of data on whether the children examined were continuous residents. Examining OPCS 1991 migration data (accessed via the Cray Supercomputer at Manchester Computing Centre) shows that the percentage of 5-year-old children who have migrated may vary between 7% and 19.5%.

b) other sources of fluoride—there is a lack of data at ward level about the use of fluoride in supplements and toothpaste. However, a recent survey of children aged 1.5–4.5 years carried out in Great Britain[24] showed that 18% of pre-school children, aged 1.5–4.5 years, have used fluoride supplements although only 6% were still taking them at the time of the survey. Furthermore, by 1992 one-third of mothers claimed they were using a lower fluoride toothpaste for their young children although it is unknown whether this tendency is higher in fluoridated districts.

c) ethnicity—the percentage of non-white residents was chosen as a variable for pairing districts to minimize any potential confounding effect. This was not successful for three pairs of districts due to the large percentage of non-white residents in three of the fluoridated districts of the West Midlands. However, as a significant number of young children resident in materially deprived areas have more dental caries than their white counterparts,[25] this would have the effect of further increasing decay experience in wards with a fluoridated drinking water supply, biasing the overall result against the effect of fluoridated water.

A greater absolute reduction in dental caries due to water fluoridation in the more deprived wards is perhaps not surprising as the underlying caries levels are greater. Figure 1 suggests that although absolute reductions in dental caries are greater in deprived than non-deprived wards the percentage reduction remains constant at approximately 50% across all ward scores. Water fluoridation thus acts to reduce health inequalities by reducing the absolute difference in caries levels between deprived and non-deprived groups. This ability of water fluoridation to reduce health inequalities may also be a function of its passive mode of delivery. Most strategies to prevent dental caries rely upon the compliance of the individual.

Whitehead[26] reviewed the effectiveness of educational approaches to reducing inequalities and suggested that programmes are unlikely to be effective with disadvantaged social and economic groups unless they are sensitive to the circumstances in which such people live, and are backed by wider policies to create a supportive environment. This suggestion is supported by Schou and Wight[27] who, evaluating dental health education campaigns in Scotland, found significant improvements in dental health in children from non-deprived schools but not in children from deprived schools, so increasing inequalities in dental health. Health inequalities have recently been highlighted by the Government in a consultative document[28] which emphasizes the importance of preventing diseases and on reducing social inequalities to improve health. The pending white paper will set out the Government's intended framework for a way forward on fluoridation which will tackle inequalities in oral health.[29]

The Oral Health Strategy for England, published in 1994 by the Department of Health,[30] sets objectives for the year 2003 for 5-year-old children. In some areas of England, especially the North West, it is unlikely that these medium-term objectives will be met unless water fluoridation is implemented. Currently, only 10% of the population of the UK receive a fluoridated water supply with the West Midlands and North East being the most extensively fluoridated regions. The Water (Fluoridation) Act 1985, now consolidated in the Water Industry Act 1991, states that water companies may fluoridate the water supplies at the request of health authorities. Many health authorities have completed the consultation and publicity required by the Act, and have made formal requests to the water company. However, most of the water companies insist that the Act gives them wide discretion in determining new schemes. To date they have refused to accede to the health authorities' requests. This study has provided further justification for amending the Water Fluoridation Act so that health authorities are better able to implement fluoridation schemes in districts with poorer dental health and the overall conclusion from this study is that water fluoridation reduces dental caries experience more in materially deprived wards than in affluent wards.

Key Messages

Water fluoridation reduces dental health inequalities, benefiting the more materially deprived communities.

Implementation of water fluoridation would help to achieve the objectives in the Oral Health Strategy for England.

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