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Community water fluoridation and health outcomes in England: a cross-sectional study

Nicholas Young[1], John Newton[2], John Morris[3], Joan Morris[4], John Langford[2], Jonathan Iloya[5], Diane Edwards[3], Semina Makhani[6] and Julia Verne[1]

[1]Public Health England, Bristol, UK, [2]Public Health England, London, UK, [3]Public Health England, Birmingham, UK, [4]Queen Mary University of London, London, UK, [5]Public Health England, Leeds, UK, [6]Public Health England, Nottingham, UK

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Abstract – *Background:* Six million people in England live in areas where the level of fluoride in water is adjusted to reduce the significant public health burden of dental caries. The dental effects of fluoride are well established, but evidence for suggested adverse health effects is limited, with a lack of rigorous small area population studies that control for confounding. This study aims to test the association between water fluoridation schemes and selected health outcomes using the best available routine data sources. *Methods:* Ecological level exposure to fluoridated water was estimated for standard small areas and administrative districts in England using Geographical Information Systems and digitized boundaries based on known patterns of water supply. The association between fluoridation and dental and nondental health indicators was tested using multivariable regression models including ecological level confounding variables. Health indicator data were obtained from routine sources. *Results:* There was strong evidence of lower prevalence of dental caries ($P < 0.001$) among children living in fluoridated areas, they also had fewer teeth affected on average ($P < 0.001$), and lower admission rates for tooth extraction (55% lower; 95% CI-73%, -27%; $P = 0.001$). There was no strong evidence of an association between fluoridation and hip fracture, Down syndrome, all-cancer, all-cause mortality or osteosarcoma. Fluoridation was negatively associated with the incidence of renal stones (7.9% lower; 95% CI-9.6%,-6.2%; $P < 0.001$) and bladder cancer (8.0% lower; 95% CI-9.9%,-6.0%; $P < 0.001$). *Conclusion:* This study uses the comprehensive data sets available in England to provide reassurance that fluoridation is a safe and highly effective public health measure to reduce dental decay. Although lower rates of certain nondental outcomes were found in fluoridated areas, the ecological, observational design prohibits any conclusions being drawn regarding a protective role of fluoridation.

Key words: epidemiology; fluoridation; public health; surveillance

Nicholas Young, Public Health England,
Bristol, UK
Tel.: 0345 504 8668
e-mail: nick.young@phe.gov.uk

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Dental caries is a significant public health problem in England, with over one-quarter of 5-year olds affected and higher rates of disease among deprived communities (1). In the early 20th century, it was observed that certain levels of naturally occurring fluoride in drinking water were associated with lower levels of dental caries, and, subsequently, the first water fluoridation scheme was introduced in the USA in 1945 in the city of Grand Rapids. The first substantive scheme in England was established for Birmingham in 1964, with six million people nationally now resident in areas where the level of fluoride in drinking water is adjusted. Fluoridation schemes in England aim to achieve a level of one part fluoride per million (ppm) in drinking water with a maximum permitted level of 1.5 ppm; additionally, some water supplies in England, serving around a third of a million people, naturally contain levels of fluoride close to 1 ppm.

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The possible health effects of fluoride in water have been extensively studied and reviewed internationally over the last fifty years (2–7); there are two known dental effects of fluoridation, reduced dental decay and dental fluorosis. A substantial range of nondental health conditions have been alleged as a consequence of water fluoridation, but there is no consistent scientific evidence to support any of these putative associations; there is a lack of high-quality studies that adjust for potential confounding variables.

This study was conducted to fulfil a statutory duty to monitor the health effects of water fluoridation arrangements in England. The objective was to compare rates of selected dental and nondental health outcomes between areas according to whether the level of fluoride in drinking water is adjusted (fluoridated) or not (nonfluoridated).

Methods

A cross-sectional ecological study was performed using English data.

Assessment of exposure

The exposure of interest was residence within an area supplied by a water fluoridation scheme. Areas where the naturally occurring fluoride level was close to 1 ppm were excluded from analyses, as they would not be subject to the exposure as defined. The overwhelming majority of fluoridation schemes were introduced in England the late 1960s or mid-1980s.

Exposure to fluoridated water was estimated for standard English small areas as used for decennial census data and known as lower super output areas (LSOAs), population range of 1000–3000 persons each, and for all administrative districts known as upper tier (UTLAs) and lower tier (LTLAs) local authorities. LTLAs can be aggregated to a smaller number of UTLAs, but some (so-called unitary authorities) carry out both roles and therefore appear in both lower and upper tier level analysis. Digitized boundaries of areas defined by a common water supply (water quality zones or WQZs) were obtained, with a binary variable attached indicating whether they were subject to a fluoridation scheme in 2012. Using Geographic Information Systems (GIS), the population-weighted centroid for each 2001 LSOA was assigned a fluoridation status – fluoridated yes/no – depending on the WQZ it was located within; LSOAs identified as being within WQZs naturally fluoridated to a level of 1 ppm were classified separately. LTLAs were considered fluoridated if >50% of their component LSOAs were within a fluoridated WQZ. Where relevant the proportion of the population covered at component LTLA level, combined with ONS population estimates, was used to assign a fluoridation status at UTLA level. Two local authority areas were known to have had fluoridation plant inactivity for an extended period of time; this was taken into account by excluding these areas from analysis at this geographical level, with the exception of a plant closure prior to 2007 that was considered to be nonfluoridated for dental outcomes in five-year olds in 2012 and Down syndrome incidence, measured from 2009 to 2012.

Confounding

Confounding variables considered are detailed in Table 1.

Index of Multiple Deprivation (IMD) 2010 scores were used to estimate deprivation. Gender (proportion male) was from the relevant Office of National Statistics (ONS) population estimates. Ethnicity, coded as white/non-white, was from the 2011 census. Age was considered as a confounder as follows; hip fracture/all-cause mortality/all-cancer – proportion >65 years old from 2010 ONS mid-year estimates; renal calculi – proportion >25 years old from 2010 ONS mid-year estimates; bladder cancer and osteosarcoma ≥50 years – proportion >65 years from ONS individual year estimates; osteosarcoma <25 years – proportion in each quinary age band from ONS individual mid-year estimates.

Outcome data

The outcomes chosen in this study were selected following a review of existing evidence and based on theoretical plausibility, potential population health impact, quality and availability of data and outcome validity.

Table 1 presents for each outcome; data source, measure, geographical level, time period, population denominator, potential confounding variables examined and case definition. All outcomes were studied by aggregating data for all fluoridated versus nonfluoridated areas.

The time-period studied for each outcome was decided *a priori*, dependent on quality and availability of robust data, expected incidence, temporal

Table 1. Health outcomes; source of data, outcome measure, geographical level, time-period studied, population denominator, confounding variables examined and case definition

Health Outcome	Source of data	Outcome measure	Geographical level of exposure	Time period	Population denominator	*A priori* potential confounders	Case definition criteria
Dental caries	National Dental Epidemiology Programme for England	Presence of caries at 5-years old and 12-years old as *mean d3mft/D3MFT* score and *prevalence of any d3mft/D3MFT*	Lower tier LA	2012 (5 year olds) 2009 (12 year olds)	ONS mid-year estimate for relevant age and year	Deprivation, ethnicity	*Mean d3mft/D3MFT* *Prevalence of any d3mft/D3mft* Clinically assessed
Admissions with Dental caries ages 1–4 years	Annual Report of the Chief Medical Officers 2012	Hospital admission with dental caries	Upper tier LA	2009–2012	ONS mid-year estimates 2009–2011	Deprivation, ethnicity	HES code K02
Hip fracture – all ages	Hospital Episode Statistics (HES)	Emergency admission; 1st or 2nd diagnosis	LSOA	2007–2013	ONS mid-year estimate 2010	Age, gender, deprivation, ethnicity	HES code S72.0–S72.2
Renal calculi -all ages	HES	Emergency admission; 1st or 2nd diagnosis	LSOA	2007–2013	ONS mid-year estimate 2010	Age, gender, deprivation, ethnicity	HES codes N20.0-N20.2; N20.9
All-cause mortality - all ages	Office of National Statistics	Death	LSOA	2009–2012	ONS mid-year estimate 2010	Age, gender, deprivation, ethnicity	Recorded death during time period
Down syndrome	The National Down Syndrome Cytogenetic Register	Incidence of Down syndrome	Lowe tier LA	2009–2012	ONS live births 2009–2012	Maternal age	All cases recorded (includes live births; stillbirth; miscarriage; terminations)
Bladder cancer – all ages	English Cancer Registration	Primary invasive bladder cancer	LSOA	2000–2010	ONS mid-year estimates 2000–2010	Age, gender, deprivation, ethnicity	ICD-10 C67
Osteosarcoma, aged <25 years; overall and subdivided by gender	English Cancer Registration	Primary osteosarcoma	LSOA	1995–2010	ONS mid-year estimates 1995–2010	Age, gender, deprivation, ethnicity	ICD-10 9180–9195 suffix 3
Osteosarcoma, aged ≥50 years	English Cancer Registration	Primary osteosarcoma	LSOA	1995–2010	ONS mid-year estimates 1995–2010	Age, gender, deprivation, ethnicity	ICD-10 9180–9195 suffix 3
Overall cancer incidence – all ages	English Cancer Registration	All excluding nonmelanoma skin cancer	LSOA	2007–2010	ONS mid-year estimate 2010	Age, gender, deprivation, ethnicity	ICD-10 C00-C97 excluding C44

HES, Hospital Episode statistics (English hospital admission records); ONS, Office of National Statistics, UK; LA, local authority (Administrative district); LSOA, lower super output area (English small area used for decennial census data).

changes in incidence and to allow a sufficient time lag from the initiation of fluoridation schemes.

Statistical methods

Statistical analysis was performed using Stata.

Hip fracture, renal calculi, all-cause mortality, bladder cancer, osteosarcoma and all-cancer.

An ecological analysis was carried out at LSOA level; for each LSOA, an outcome count was produced by combining individual case data for the entire time period. Initial descriptive analysis was followed by calculation of the crude rate (incidence density) by fluoridation status.

Negative binomial models, chosen as there was evidence of over-dispersion in count data, were used to model the association between fluoridation status and outcome; counts were offset against the (natural logarithm of) relevant denominator population. Following univariate analysis, multivariable models were constructed to test the association between fluoridation status and the outcome adjusted for *a priori* confounding variables.

All confounding variables were divided into quintiles and included as nonordered categories so as not to assume any underlying distribution between these exposures and the outcome.

A reverse stepwise procedure was employed to build the final multivariable model. All confounding variables were initially included, then removed in order of those with the weakest association with the outcome first; variables were retained if exclusion altered the association between fluoridation and outcome – using a guide of 10% – or the *P*-value for a likelihood ratio test comparing models was <0.1.

Osteosarcoma was considered as an outcome separately for those aged <25 years and ≥50 years, reflecting the bimodal distribution of incidence and aetiology (8). For those <25 years, subgroup analysis by gender was performed in consideration of a suggested age-specific effect (9, 10).

Ethnicity data were taken from the 2011 census as 2001 data would have been subject to considerable change prior to the collection of outcome data. Between 2001 and 2011, the boundaries of some LSOAs were altered to take into account population change; therefore, final models were produced with and without ethnicity to reflect these anomalies.

Down syndrome

The outcome used was the count of all cases of Down syndrome, including live births, stillbirths (≥24 weeks' gestation), late miscarriages (20–23 weeks' gestation), terminations of pregnancy with foetal anomaly. To adjust for differences in LTLA maternal age distribution, the total number of births for each year of maternal age was multiplied by the relevant Down syndrome birth risk to estimate the expected number of affected births for mothers of that age; the total number of expected Down syndrome births for each LTLA was calculated by summing the expected numbers (11).

Univariate analysis was performed with the total number of live births in each LTLA as the exposure using a Poisson model, followed by a model with the expected number of Down syndrome births as the exposure to adjust for maternal age.

Dental caries experience and related hospital admissions

The outcome used was the experience of dental caries, expressed in terms of the mean number of decayed, missing and filled primary (*dmft)* and permanent (*DMFT*) teeth and the percentage with experience of decay (*% dmft/DMFT*>0 – *prevalence of d3mft/D3MFT*). These data were obtained from the most recent surveys of five (2012) (1) and 12-year-old children (2009) (12) undertaken for the National Dental Epidemiology Programme. The programme involves visual examination of school children for missing teeth (mt/MT), filled teeth (ft/FT) and teeth with obvious decay into dentine (d3t/D3T) as denoted by the figure 3 which indicates this level of detection (indicated as *d3mft/D3MFT*).

Analysis was carried out at LTLA level. Summary statistics, crudely, then weighted by LTLA individual year (5 or 12 years old) population, were calculated aggregated by fluoridation status, larger weighting given to greater population sizes.

Univariate analysis was used to test the association between fluoridation and outcome, followed by the construction of multivariable models. Deprivation and ethnicity, considered to be *a priori* confounders, were coded into quintiles and included as ordered or nonordered categorical variables depending on visual inspection of box plots and likelihood ratio test between models containing the independent variables in different forms. A reverse stepwise procedure was used as previously outlined.

Weighted linear regression was used to test the association between fluoridation status and *mean d3mft/D3MFT* as a continuous variable; the association between fluoridation and *prevalence of d3mft/*

D3MFT was tested using generalized linear models (binomial distribution), weighted using analytical weights, with robust standard errors.

Analysis of hospital admission records (hospital episode statistics or HES) for children aged 1–4 years admitted with a primary diagnosis code of KO2 (dental) was carried out at UTLA level. Negative binomial models were used to model the association between fluoridation status and the count of admissions, using the (natural logarithm of) relevant population as the offset. Deprivation and ethnicity were considered as potential confounding variables as outlined previously in this section.

For all dental outcomes, an *a priori* interaction between deprivation quintiles and fluoridation status was tested, followed by an exploratory analysis with deprivation coded as binary; the most deprived quintile compared with the combined four least deprived quintiles. A test for interaction was then performed using a likelihood ratio test between models with and without inclusion of an interaction term. For the *prevalence of d3mft/D3MFT*, a test for interaction could not be performed using models with robust standard errors; therefore, if the effect of fluoridation appeared to differ between the most deprived and the combined four least deprived quintiles, stratum-specific estimates were also presented.

Results

Table 2 presents fluoridation data by geographical level. Of 32 482 LSOAs (2001 boundaries) in England, 3991 (12.3%) were considered fluoridated; 58 (0.2%) were considered naturally fluoridated.

Nondental health indicators

Table 3 presents the incidence of nondental health outcomes and association with fluoridation in univariate and multivariable analyses.

Multivariable analysis did not demonstrate any evidence of any association between fluoridation and hip fractures, all-cancer, or osteosarcoma including subgroup analysis, whereas there was some evidence of a negative association between fluoridation and all-cause mortality (1.3% lower; 95% CI-2.5%,-0.1%; $P = 0.04$).

There was strong evidence that the rate of renal calculi was lower in fluoridated areas than nonfluoridated areas following adjustment for age, gender and deprivation (8.4% lower; 95% CI-10%,-6.7%; $P < 0.001$) and following additional adjustment for ethnicity (7.9% lower; 95% CI-9.6%,-6.2%; $P < 0.001$).

Following adjustment for age, gender and deprivation, there was strong evidence that the rate of bladder cancer was lower in fluoridated areas (8.6% lower; 95% CI-11%,-6.7%; $P < 0.001$); this negative association was maintained after additional adjustment for ethnicity (8.0% lower; 95% CI-9.9%,-6.0%; $P < 0.001$).

The incidence of Down syndrome was lower in fluoridated than nonfluoridated areas, but following adjustment for maternal age, there was no evidence of any association (1.7% higher; 95% CI-6.2%, 10%; $P = 0.68$); the average maternal age was higher in the nonfluoridated LTLAs (29.3 years; 95% CI; 29.30, 29.31) than fluoridated LTLAs (28.4 years; 95% CI; 28.37,28.41).

Dental data

Table 4 presents the weighted *mean d3mft/D3MFT* and weighted *prevalence of d3mft/D3MFT* by fluoridation status for 5 and 12 year olds. There was

Table 2. Fluoridation status by geographical level as a binary variable and by extent of coverage

		Geographical area		
Exposure classification	Fluoridation	Lower super output area	Lower tier Local authority	Upper tier Local authority
Binary	Yes	3991 (12.3%)	34 (10.7%)	14 (9.2%)
	No	28 433 (87.5%)	291 (89.3%)	137 (90.1%)
	Natural	58 (0.2%)	1 (0.3%)	1 (0.7%)
Categorical	100% Coverage	n/a	25 (8.0%)	12 (7.9%)
	>50%		9 (2.8%)	2 (1.3%)
	≤50%		11 (3.4%)	11 (7.2%)
	None		280 (85.9%)	126 (82.9%)
Total		32 482	326	152

Table 3. Nondental health outcomes by fluoridation status, results of univariate and multivariable analysis

Outcome	Exposure status	Person-years at risk (pyar)	Number of cases	Crude rate per 100 000 pyar	Crude incidence rate ratio (IRR) (%)[a]	Incidence rate ratio (%)[a] (IRR) adjusted for age, gender, IMD (%) $n = 32424$	P-value	IRR adjusted for age, gender, IMD, ethnicity (%)[a] $n = 31619$	P-value
Hip Fracture 2007–2013 (6 years)	F	37 971 918	45 219	119	7.2 (4.9, 9.6)	0.9 (−0.8, 2.6)	0.29	0.7 (−1.0, 2.4)	0.42
	Non-F	274 884 530	303 848	111					
Renal calculi 2007–2013 (6 years)	F	37 971 918	18 579	48.9	−5.3 (−7.1, −3.5)	−8.4 (−10, −6.7)	<0.001	−7.9 (−9.6, −6.2)	<0.001
	Non-F	274 884 530	141 963	51.6					
All-cause mortality 2009–2012 (4 years)	F	25 314 612	233 922	924	5.2 (3.4, 7.0)	−1.4 (−2.6, −0.3)	0.02	−1.3 (−2.5, −0.1)	0.04
	Non-F	183 256 350	1 602 206	874					
Bladder cancer 2000–2010 (11 years)	F	67 978 298	11 327	16.7	−4.4 (−6.7, −2.1)	−8.6 (−11, −6.7)	<0.001	−8.0 (−9.9, −6.0)	<0.001
	Non-F	487 149 150	84 780	17.4					
All-cancer 2007–2010 (4 years)	F	25 314 612	131 288	519	2.7 (1.4, 4.0)	−1.1 (−1.9, −0.3)	<0.01	−0.4 (−1.2, 0.4)	0.29
	Non-F	183 256 350	921 583	503					
Osteosarcoma under 25 years – all 1995–2010 (16 years)	F	31 313 151	148	0.47	8.0 (−9.3, 29)	6.6 (−11, 27)	0.48	8.2 (−9.3, 29)	0.38
	Non-F	216 921 400	949	0.44					
Osteosarcoma under 25 years – male 1995–2010 (16 years)	F	15 981 438	92	0.58	18 (−5.4, 48)	16 (−11, 27)[b]	0.20	17 (−7.1, 46)[b]	0.19
	Non-F	110 831 320	540	0.49					
Osteosarcoma under 25 years – female 1995–2010 (16 years)	F	15 331 713	56	0.37	−5.3 (−29, 26)	−4.7 (−28, 27)[b]	0.74	−2.5 (−27, 30)[b]	0.86
	Non-F	106 090 080	409	0.39					
Osteosarcoma 50 years and over 1995–2010 (16 years)	F	33 080 465	73	0.22	−12 (−31, 13)	−10 (−30, 15)	0.38	−15 (−34, 9.6)	0.21
	Non-F	232 282 090	587	0.25					
Down Syndrome 2009–2012 (4 years)	F	303 818	658	217	−12 (−19, −4.3)[c]	1.7 (−6.2, 10)[c,d]	0.68	n/a	n/a
	Non-F	2 423 482	5961	246					

F, fluoridated; Non-F, nonfluoridated.

[a] Incidence rate ratios (IRR) and confidence intervals are expressed as a percentage increase in observed rate, for example an IRR(%) of 7.2 (4.9, 9.6) equates to an IRR of 1.072 (1.049, 1.096) times.

[b] Not adjusted for gender.

[c] Odds ratio (%), for Down syndrome outcome only.

[d] Adjusted for maternal age only and at lower tier local authority level ($n = 324$).

Table 4. Dental outcomes, weighted mean d3mft/D3MFT and prevalence of d3mft/D3MFT by fluoridation status, results from univariate and multivariable analysis

		Mean d3mft/D3MFT				Prevalence of any d3mft/D3MFT			
Age group	Exposure status	Weighted mean d3mft/D3MFT	Crude difference (number of teeth)	Adjusted for deprivation and ethnicity	*P*	Weighted prevalence of d3mft (%)	Crude odds ratio (%)	Odds ratio adjusted for deprivation and ethnicity (%)	*P*
5-year olds	F	0.81 (0.71,0.90)	−0.20 (−0.36, −0.04)	−0.37 (−0.48, −0.27)	<0.001	26 (24,28)	−15 (−29, 2.5)	−28 (−35, −21)	<0.001
	Non-F	1.01 (0.95,1.07)				29 (28,30)			
12-year olds	F	0.65 (0.61,0.69)	−0.10 (−0.20, −0.01)	−0.19 (−0.27, −0.11)	<0.001	31 (30,33)	−11 (−20, −0.1)	−21 (−12,−29)	<0.001
	Non-F	0.76 (0.72,0.79)				34 (33,35)			

F, fluoridated; Non-F, nonfluoridated.

strong evidence that, adjusted for deprivation and ethnicity, *mean d3mft/D3MFT* was lower in fluoridated areas for 5 years olds (−0.37; 95% CI-0.48, -0.27; *P* < 0.001) and 12 year olds (−0.19; 95% CI-0.27, -0.11; *P* < 0.001). Likewise in multivariable models, the weighted odds of *prevalence of d3mft/D3MFT* were 28% lower (95% CI-35, -21) in five-year olds and 21% (95% CI-12, -29) lower in 12-year olds.

The median rate of admission in nonfluoridated areas was 370 per 100 000 person-years at risk (pyar) and 42 per 100 000 pyar in fluoridated areas. The rate of admission in fluoridated areas was 45% lower than in nonfluoridated areas (95% CI-68%, -6%; *P* = 0.03); following adjustment for deprivation, there was strong evidence that the rate of admission was lower in fluoridated than nonfluoridated areas (55% lower; 95% CI-73, -27%; *P* = 0.001). Ethnicity did not fulfil criteria for inclusion in final models. There was some evidence of an interaction between fluoridation status and deprivation across all quintiles (*P* = 0.05) and weak evidence (*P* < 0.1) when comparing the most deprived to the combined four least deprived quintiles; the rate of admission was 27% lower (95% CI-62%, 39%; *P* = 0.34) in fluoridated areas than nonfluoridated areas in the combined four least deprived quintiles, and 76% lower (95% CI-89%, -45%; *P* = 0.001) in the most deprived quintile.

Considering *mean d3mft/D3MFT*, there was no evidence of an interaction between fluoridation status and deprivation across all quintiles in 5-year olds (*P* = 0.15) and 12-year olds (*P* = 0.64). There was evidence that the association between fluoridation and *mean d3mft/D3MFT* was different in the most deprived quintile of deprivation than the combined four least deprived quintiles in 5-year olds (*P* < 0.01) and 12-year olds (*P* = 0.02). In 5-year olds, stratum-specific estimates demonstrated that *mean d3mft* was 0.16 lower (95% CI-0.32, -0.01; *P* = 0.04) in fluoridated areas in the combined four least deprived quintiles and 0.51 lower (95% CI-0.75, -0.27; *P* < 0.001) in the most deprived quintile. In 12-year olds, *mean D3MFT* was 0.07 lower (95% CI-0.17, 0.04; *P* = 0.21) in fluoridated areas than nonfluoridated areas of the combined four least deprived quintiles, whereas this mean score was 0.25 lower (95% CI-0.44, -0.07; *P* < 0.01) in fluoridated areas of the most deprived quintile.

Stratum-specific estimates demonstrated that in the combined four least deprived quintiles the odds of *prevalence of d3mft/D3MFT* were 17% lower (95% CI-28%, -3.9%; *P* = 0.01) in 5-year olds and 9%

lower (95% CI-21%, 5%; $P = 0.21$) in 12-year olds in fluoridated areas; in the most deprived quintile, the *prevalence of d3mft/D3MFT* was 32% lower (95% CI-42%, -19%; $P < 0.001$) in 5-year olds and 26% lower (95% CI-40%, -8%; $P < 0.01$) in 12-year olds.

Discussion

There was no evidence in this study of any detrimental health effects associated with residence in areas with fluoridation schemes. There was strong evidence that residence in fluoridated areas was associated with lower rates of childhood dental caries and reduced numbers of hospital admissions for dental extraction in young children.

The main limitations of this report reflect the use of routinely available data and an ecological level analysis, potentially resulting in confounding and failure to detect effects that are only seen at individual level and not at the level of whole populations (the ecological fallacy). Additionally, there was potential for misclassification of exposure status.

The relative risk from environmental exposures is typically low; effects can be dominated by strongly associated independent variables such as age, smoking and deprivation (13). Although considerable attempts were made to control for confounding using routinely available data, potential nuisance effects, both residual and from variables not adjusted for (e.g. smoking), remain, raising uncertainty in the presence, and to some extent absence, of associations found.

The ecological level associations in this report may not reflect the true relationship between fluoridation and health at an individual level; for example, the lower rate of bladder cancer in fluoridated areas cannot be taken to mean a lower individual risk with increased personal fluoride consumption (14).

Use of an ecological level fluoridation measure, reflecting the intervention, does not take into account individual tap water consumption and intake from other dietary sources and dentifrices. Migration, temporal changes in water quality zone boundaries and fluoride levels, 'halo' effects from neighbouring areas and the presence of varied levels of natural fluoridation can all introduce additional misclassification bias, with the likely effect of reducing the strength of any associations (15). In the year ending June 2013, 2.71 million people in England and Wales moved between local authorities, equating to 4.8% of the population; the age with the highest proportion of movers was 19 years (16).

The majority of fluoridation schemes have been in place for over thirty years, but there are more recent programmes. This monitoring report did not stratify by the duration of the fluoridation scheme, which would represent an exploratory analysis in the absence of clear biological mechanisms for putative nondental effects.

Despite these limitations, the use of GIS in this study to determine fluoridation of tap water at small area level represents a considerable improvement on many previous ecological studies (17–21). The routine data used to measure health outcomes were robust and comprehensive.

In this study, a significantly lower prevalence of dental caries was observed among children living in fluoridated areas; the effects seen are of considerable public health significance and are consistent with previous international studies (2–4, 6, 7). Additionally, there is a suggestion that the effect is greater within the most deprived communities. The lower rates of dental admissions in fluoridated areas are likewise of public health and economic significance, although some caution should be exerted as there are potential problems with data quality. An evaluation of dental general anaesthetics in an English region found inconsistencies in using HES coding systems, also potentially occurring in other regions; therefore, the admissions data used may not be fully comparable between areas (22). Although there is no reason to suppose that services in fluoridated areas are likely to record this activity differently to services in nonfluoridated areas, further work to improve data quality is recommended. Given that children from deprived communities are less likely to practice good oral hygiene and access dental services for routine care, the large effect on childhood dental admissions may reflect primary prevention overcoming significant disadvantages experienced.

Consistent with previous evidence, this study did not find an evidence of an association between fluoridation and hip fractures (2, 5, 19, 23, 24), all-cause mortality (2), Down syndrome (25) and all-cancer (2, 7). There was some evidence of a negative association between fluoridation and all-cause mortality, but in the presence of a very large sample size and number of events, combined with the small effect size seen, this finding is unlikely to be of significance.

A positive association between fluoride ingestion and osteosarcoma has been mooted, but the evidence is limited in extent and validity (2). The absence of any association between fluoridation and osteosarcoma in our study is consistent with the majority of previous case–control and ecological level studies (26–33). A single animal study and case–control study have suggested a gender-specific association between fluoride and osteosarcoma, a finding not supported by our subgroup analysis (9, 10).

A recent UK ward-level ecological study using a broadly similar method to this study found no association between measured fluoride levels in drinking water and osteosarcoma (31).

This report demonstrated a lower incidence of bladder cancer in fluoridated than nonfluoridated areas. Previous ecological level research from Taiwan, considering natural fluoridation, concluded that there was unlikely to be an association between fluoridation and bladder cancer (34). Bladder cancer risk is higher in men and increases dramatically with age; adjusting for these variables at an ecological level may have resulted in residual confounding in the association between fluoridation and this outcome. Smoking is a powerful independent risk factor for bladder cancer and was not adjusted for because of a lack of robust data.

The negative association demonstrated between fluoridation and renal calculi is consistent with one, but not all, previous ecological studies (17) and should be treated with caution. Renal stones are associated with age, co-morbidity and lifestyle factors including diet (35); the association seen may simply reflect these differences; further research would be required to investigate any relationship.

This study did not examine dental fluorosis; it is not routinely reported in small area level dental surveys. Recent English research comparing a fluoridated to a nonfluoridated city demonstrated a low prevalence of moderate and severe forms of dental fluorosis in both areas (36).

The study uses the comprehensive routine data sources and national dental surveys available in England to provide further reassurance that water fluoridation is a safe and effective public health measure to reduce the significant burden of dental caries.

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