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A comparison of dental fluorosis in adult populations with and without lifetime exposure to water fluoridation

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Abstract

Objectives: There is a lack of evidence on the proportion and severity of fluorosis in adult populations exposed and not exposed to fluoridated water over their lifetimes. The aim of this study was to compare the proportion and severity of fluorosis in adults with lifetime exposure to water fluoridation with a nonexposed sample. A secondary aim was to report the gradient of fluorosis severity by age.

Methods: A cross-sectional study recruited a sample with lifetime exposure to water fluoridation and a matched, nonexposed group. 580 participants, aged 18-52 years (mean 34.3, SD 9.4) and 64% female, were recruited in general dental practices located in fluoridated (Birmingham and County Durham) and nonfluoridated areas (Manchester). Three digital images were taken of their incisors and an experienced examiner who was blind to exposure status viewed the images remotely and allocated fluorosis scores using the Thylstrup and Fejerskov (TF) scale.

Results: At TF $\geq$ 1 (any fluorosis), a significantly higher proportion of participants from the fluoridated area had fluorosis (F 39% NF 21.3%, $P < 0.001$), at the threshold TF $\geq$ 3 ("aesthetic concern"), the difference was no longer statistically significant (F 4.1%, NF 2.2%, $P = 0.25$). There was a gradient by age, whereby fluorosis was highest in the youngest and lowest in the oldest age group.

Conclusions: Although fluorosis is more common in adults with lifetime exposure to water fluoridation than those with no exposure, the aesthetic impact of fluorosis seems to diminish with age.

KEYWORDS
adults, fluoridation, fluoride, fluorosis, public health

1 | INTRODUCTION

Dental fluorosis is cited as the most significant risk of community water fluoridation.[1,2] Fluorosis presents within a spectrum of severity, its mild forms appearing as white or translucent mottling or banding of teeth while more severe cases involve pitting and enamel damage.[3,4] There exists an association (biological gradient) between fluorosis severity and exposure to fluoride, particularly during the maturing of the dentition of children.[5] However, significant gaps in the literature exist in the area of adult fluorosis and, in particular, whether the appearance of fluorosis changes with age.[6-9] Groups opposed to fluoridation of water supplies often cite fluorosis as a reason for ceasing existing schemes and rejecting new proposals.[4]

Many studies report the effects of fluorosis to be purely aesthetic, and that minor presentations of fluorosis are not of great concern to those affected.[10-14] The links between fluorosis and psychosocial factors are limited; for example, Chankanka et al[11] reported that at mild and moderate levels of fluorosis, there were no negative effects on oral health-related quality of life in countries with community water fluoridation (USA, UK, Canada and Australia).

Only 10% of the UK population receive optimally fluoridated water (either artificially or naturally) and the first UK water fluoridation schemes date back to the mid-1960s.[15] Accordingly a population exists who have had a lifetime exposure to water fluoridation and it should be feasible to investigate the impact of water fluoridation on the occurrence of fluorosis amongst adults. Two recent, studies comparing fluorosis occurrence amongst 11-14 years old in fluoridated and nonfluoridated areas of the UK report a percentage difference of 31% and 24% for any fluorosis, and 3% and 8% for aesthetically objectionable fluorosis.[5,8] We have little or no understanding of whether levels of fluorosis in adults with lifetime residence in fluoridated and nonfluoridated areas are of similar magnitudes to those seen in children. Moreover, it is biologically plausible, given the superficial nature of the less severe presentations of fluorosis, that long-term tooth brushing with toothpaste (abrasion) and consumption of erosive drinks and foodstuffs will reduce the severity of fluorosis with age.[16] It is also possible that in fluoride-rich environments (such as those produced by the use of higher fluoride toothpastes) remineralization of the hypomineralized lesions may occur.

Systematic reviews have identified this dearth of literature reporting the effects of water fluoridation on caries and fluorosis in adulthood.[2,7,17,18] One study investigated adults and identified significantly more fluorosis in a population with higher levels of fluoride in the water supply. However, the concentration of fluoride in the water supply in this study was 3.5 ppm, much higher than optimally fluoridated community schemes in the UK,[19] where 0.7-1 ppm is typical and this could account for the findings. Fluoride exposure is not exclusively due to fluoridated water; other sources such, as toothpastes or professionally applied fluoride, are now significant contributing factors.[20-22] A longitudinal, population-based, study of Australian children, aged 8-13 years, prospectively followed-up participants after 8 years and reported a 55% reduction of fluorosis at the TF 2 or 3 level.[16] While providing strong evidence of mild dental fluorosis diminishing over this time period, the question of the association between water fluoridation and fluorosis over a longer period or lifetime remains. If fluorosis does diminish with age, then the public health concerns of fluorosis could be mitigated and a potential concern blocking the expansion of water fluoridation schemes removed.[16]

This study recruited patients attending general dental practices and aimed to report the proportion of fluorosis in adults with lifetime residency in communities receiving fluoridated water and make comparisons to a matched sample form a nonfluoridated locality. In addition, the gradient of fluorosis severity across age groups was investigated to determine whether fluorosis is highest in younger and lowest in older age groups.

2 | METHODS

Ethical approval was provided by the Hampshire Research Ethics Committee (16/SC/0672). Participants were recruited from February to June 2017. The STROBE checklist has been adhered to during the reporting of this study.[23]

The setting for the study was National Health Service (NHS) general dental practices located in three areas of the UK. The water supply of two of these areas, Birmingham and County Durham, has been continuously fluoridated since 1964 and 1968 respectively, at a target level of 1.0 ppm. The comparison area of Greater Manchester has always had a nonfluoridated water supply. A two-stage recruitment process was used. Firstly, practices were selected pragmatically to recruit a high proportion of patients with lifetime residency, avoiding practices with transient populations (such as higher education students) and those on the border of the fluoridated localities. Large NHS dental practices were used in order to facilitate greater efficiency in recruitment, to ensure that sufficient space was available for digital imaging of participants and the support of a practice manager was also desirable.

The second stage of recruitment was at the participant level, where the inclusion criteria were adult patients (18 years and over); an upper age limit of 52 years in Birmingham and 48 years in County Durham (based on the starting date of the respective fluoridation schemes); having at least two unrestored or minimally restored anterior maxillary incisors; and being able and willing to provide informed consent to the study. Patients were excluded where they could not confirm lifetime residency of the area. This resulted in an opportunistic sample from fluoridated areas, which was completed prior to commencement of recruitment in the nonfluoridated locality. The comparison group was matched on a frequency basis according to age and level of deprivation. This was completed by calculating the proportion of recruited participants belonging to 5-year age groups (18-22, 23-27, 28-32, 33-37, 38-42, 43-47, 48-52). The necessary numbers of patients were then recruited in the nonfluoridated area to mirror these proportions. Deprivation matching was completed in an identical manner to ensure that an equal proportion of participants were recruited for each Index of Multiple Deprivation (IMD) decile. IMD measures relative deprivation for geographical areas with a population of between 1000 and 1500 in England, based on income, employment, education, health, crime, housing and environment.[24] The IMD can be analysed in deciles with 1 being the most deprived and 10 the least. The proportion of recruited patients within each decile of the fluoridated group was matched in the comparison group by targeting practices and participants living in the nonfluoridated locality.

2.1 | Study procedures

Designated study sessions were selected where there was a high throughput of potentially eligible patients; this also enabled the research team to plan their attendance and set up the photographic equipment. The dental practices' list of patients due a routine examination was interrogated by dental practice staff and potentially eligible participants were identified. One week prior to the study sessions, dental practice staff issued a letter of invitation and information sheet to the selected patients who met the age range of the inclusion criteria. On arrival at the practice, patients were reminded of the study by dental practice staff or members of the research team. Interested patients were taken to a private room where further details could be provided and questions answered. Lifetime residency was verbally confirmed during an interview with a researcher who then sought formal written consent. The completion of consent and the imaging procedure lasted a maximum of 10 minutes. Concurrently a data collection sheet was completed with the participant's date of birth, postcode, sex and ethnicity (classified as White British/Irish, Mixed Race, Asian British, Black British/African or Other). The imaging procedure consisted of participants retracting their lips with a lip retractor, after which their teeth were dried with cotton wool for 10 seconds and three images taken using a camera system specifically developed for measuring fluorosis in research projects.[25,26] The camera was attached to a stabilization frame and the participant rested their chin on the frame to ensure a static position and provide consistency in imaging. The imaging system was fitted with a high-resolution 3CCD FireWire camera and white light D65 LED arrays. The white light was cross-polarized to remove the specular reflections on the images. This system was connected to a computer with custom software which controlled white light intensity, and captured and saved the dental images.

2.2 | Sample size

At a 0.05 significance level 80% power, a sample of 181 in each group (lifetime water fluoridation exposure/no exposure) was sufficient to detect a 6.2% difference in the proportion with fluorosis of aesthetic concern (TF $\geq$ 3), between the exposed and nonexposed samples. The percentage difference used in this calculation is the result reported in a recent study completed in similar areas of the UK, but in children aged 11-14 years.[5] The sample size was applied to the three areas with over-recruitment, to ensure that sufficient numbers were present to compensate for unscorable images.

2.3 | Fluorosis scoring

Fluorosis was measured using the Thylstrup and Fejerskov (TF) scale, which is reported to provide biological validity and mirror histological methods.[27] The diagnostic thresholds of TF $\geq$ 1 and TF $\geq$ 3 were used, with the former allowing the identification of any level of fluorosis and the latter focusing on fluorosis of aesthetic concern.[10-12] This was assessed by uploading the images captured on the camera system to a secure website and granting access to a single experienced examiner (MM) who viewed them remotely in a randomly generated order and scored the images using the TF index.[4] This process ensured examiner blinding with regard to each participant's exposure to fluoridated water. A score for each of the maxillary incisors was recorded and an overall score at the participant level was recorded according to the highest score where two or more teeth scored at that level. The association between fluorosis and age was investigated by calculating fluorosis scores by age band; in addition, the sample was grouped according to the age threshold of ≥40 years.

2.4 | Statistical analysis

Data were exported from the website to SPSS (IBM Corp. Version 23, Armonk, NY, USA: IBM Corp.). Descriptive analyses were completed for fluoridated and nonfluoridated groups and reported for: age, sex, level of deprivation, ethnicity and fluorosis levels. Assumptions for parametric tests were not met, so Mann–Whitney *U* and chi-square tests were utilized to test the statistical significance of observed differences in fluorosis levels in fluoridated and nonfluoridated areas, with a significance level of 0.05 applied. A logistic regression model was used to assess the possible associations between the presence of fluorosis (at the TF1 level) and the variables of water fluoridation, age, sex, IMD and ethnicity; the number of participants with fluorosis at an aesthetic level (TF3) was not large enough to substantiate a regression model.

3 | RESULTS

A total of 580 participants were recruited, 383 (66%) in fluoridated and 197 (34%) in nonfluoridated areas). The final sample did not include 28 participants due to there being fewer than two anterior maxillary incisors or because imaging was not possible due to the presence of veneers or orthodontic devices.

The socio-demographic profile of the fluoridated and nonfluoridated samples is summarized in Table 1. The final sample comprised 552 participants of whom 64% were female; 369 participants had lifetime residency in an area with fluoridated water. The age distribution showed a range from a minimum of 18 years to a maximum of 52 years of age. There was no significant difference in the age and IMD distribution of the exposed and comparison samples, and both samples had higher proportions of the more deprived IMD deciles.

Table 2 presents the TF scores at TF1 and TF3 levels according to fluoridation status. The proportion of fluorosis at the aesthetic level (TF3) is <5% for both fluoridated and nonfluoridated areas and shows no statistically significant difference. At the any fluorosis level (TF1), there is a difference between proportions of disease of 18% ($P < 0.05$).

Table 3 reports the proportions of fluorosis for groups under 40 and ≥40 years in both fluoridated and nonfluoridated areas. Fewer participants were identified with fluorosis in the 40 years and over group. The mean TF scores across the 5-year interval age groups is presented in Table 4, this highlights the age gradient, whereby mean TF was lower in the older age groups. Although the TF scores are ordinal, the mean and standard deviation have been presented as the median was zero for all groups and fails to identify the gradient across age groups.

The logistic regression model (Table 5) provides evidence to support the association between any fluorosis (TF1) and the variables of age ($P < 0.01$) and water fluoridation ($P < 0.01$).

TABLE 1 Characteristics of the study participants, n (%)

	Fluoridated area	Nonfluoridated area	Total
Total number	369 (66.8%)	183 (33.2%)	552
Male	124 (34%)	75 (41%)	199 (36%)
Female	245 (66%)	108 (59%)	353 64%)
Mean age[a] (years) (SD)	34.16 (9.3)	34.36 (9.4)	34.29 (9.4)
Level of deprivation – IMD[b] decile[c]			
1	82 (22.2%)	41 (22.4%)	123 (22.3%)
2	50 (13.6%)	24 (13.1%)	74 (13.4%)
3	66 (17.9%)	33 (18.0%)	99 (17.9%)
4	57 (15.4%)	27 (14.8%)	84 (15.2%)
5	29 (7.9%)	15 (8.2%)	44 (8.0%)
6	33 (8.9%)	16 (8.7%)	49 (8.9%)
7	24 (6.5%)	11 (6.0%)	35 (6.3%)
8	13 (3.5%)	7 (3.8%)	20 (3.6%)
9	10 (2.7%)	6 (3.3%)	16 (2.9%)
10	5 (1.4%)	3 (1.6%)	8 (1.4%)
Ethnicity[d]			
White British/ Irish	345 (93.5%)	142 (77.6%)	487 (88.2%)
Mixed race	7 (1.9%)	10 (5.5%)	17 (3.1%)
Asian British	4 (1.1%)	13 (7.1%)	17 (3.1%)
Black British/ African	9 (2.4%)	11 (6.0%)	20 (3.6%)
Other	4 (1.1%)	7 (3.8%)	11 (2.0%)

[a] $P = 0.683$ Mann–Whitney: $U = 32\ 937$, $z = -0.47$, $r = -0.02$.
[b] Index of multiple deprivation.
[c] $P = 0.908$ Mann–Whitney: $U = 33\ 562$, $z = -0.12$, $r = 0.00$.
[d] $P = 0.000$ Mann–Whitney: $U = 28\ 410$, $z = -5.44$, $r = -0.23$.

4 | DISCUSSION

This is the first fluorosis study comparing lifetime residents of fluoridated and nonfluoridated adult samples in a general dental practice setting. It confirms a higher proportion of fluorosis, at all levels, in lifetime residents of water-fluoridated areas. However, at levels considered to cause aesthetic concern (TF3 and above), fluorosis in the fluoridated sample is minimal (4.1%) and not statistically significantly different from the comparator nonfluoridated sample. Our findings also suggest that the severity of fluorosis may reduce with age.

The strengths of this study lie in the frequency matching of the intervention and comparison samples by age and deprivation, which ensured that correction for these confounders was completed by design, rather than in post hoc analysis. The imaging method ensured the blinding of the examiner to participant exposure to water fluoridation, this technique has been tested and calibrated with successful results[28,29] and has become well established through utilization in other research studies.[5,25,26] Using images dictated that only incisors were used for scoring; this was considered acceptable because on an aesthetic level, these are the teeth that are most important.[14]

There were a number of weaknesses in the study, most of which would be encountered by any study investigating the long-term effects of exposure to water fluoridation in an adult population. The main weakness is that the sample was recruited in general dental practices; this resulted in a sample that is not necessarily generalizable to fluoridated and nonfluoridated UK populations because of the different characteristics of people who are regular and irregular dental attenders.[30] We chose to conduct the study in a general dental practice setting in which an adult population could be easily recruited and could accommodate the technical equipment to capture standardized images of the participants' teeth. We also restricted recruitment to individuals with a lifetime exposure/no exposure to water fluoridation and did not account for migration in and out of fluoridated areas. One could hypothesize that the proportions of participants with fluorosis would be overestimated when recruiting such people because regularly attending, oral-health conscious patients are more likely to have a higher fluoride exposure because of their greater exposure to professionally applied and self-administered fluorides. The opportunistic approach to recruitment and the frequency-based matching methods could also have introduced selection bias. However, participants were approached consecutively from the list of patients booked in for routine appointments; on any day where the research team was in attendance and there was no potential for participant selection to be influenced by fluorosis levels. The sample incorporated the full spectrum of ages, as dictated by the water fluoridation schemes, and was representative of the local socio-economic background. The selection methods may not necessarily have provided a representative sample for precise fluorosis population prevalence statistics; however, the matching process provided similar samples to enable valid comparisons of fluorosis levels between the exposed and nonexposed samples.

There is potential for nonresponse bias, yet there was no evidence that patients participated because they had fluorosis or were motivated to participate by the presence or absence of water fluoridation. Reasons for nonparticipation were being too busy, concerned about the use of the lip retractor, experiencing pain, not interested in research and deterred by their (non fluorosis related) appearance (eg, orthodontic or restorative need). The age of 40 years was used

TABLE 2 Frequency of fluorosis at thresholds of any fluorosis (TF ≥ 1) or aesthetic concern (TF ≥ 3), n (%)

	TF < 1	TF ≥ 1	TF < 3	TF ≥ 3
Fluoridated water	225 (61%)	144 (39%)	354 (95.9%)	15 (4.1%)
Nonfluoridated water	144 (78.7%)	39 (21.3%)[a]	179 (97.8%)	4 (2.2%)[b]

[a] χ^2 (1) = 17.32, $P < 0.05$.
[b] χ^2 (1) = 1.30, $P > 0.05$.

TABLE 3 Proportions of fluorosis at any fluorosis level (TF ≥ 1) or aesthetic level (TF ≥ 3) grouped at the 40 y of age threshold

	Age	TF < 1	TF ≥ 1	TF < 3	TF ≥ 3
Fluoridated area	<40	141 (55.7%)	112 (44.3%)	239 (94.5%)	14 (5.5%)
	≥40	84 (72.4%)	32 (27.6%)	115 (99.1%)	1 (0.9%)
Nonfluoridated area	<40	100 (75.2%)	33 (24.8%)	130 (97.7%)	3 (2.3%)
	≥40	44 (88.0%)	6 (12.0%)	49 (98.0%)	1 (2.0%)

as a threshold in the analysis because those born after the late 1970s (and therefore under 40 years of age) would have had greater exposure to other sources of fluoride, especially fluoride toothpaste in early childhood and in later years through the greater use of fluoride varnish.[31,32] An attempt to gather fluoride exposure through questionnaires during this cross-sectional study would have provided current behaviour but not necessarily historical use of toothpaste or other fluoride sources, and so was not used. It was also not possible to collect information on past dental treatment history which could have affected the results. For example, children exposed to fluoride could have had micro-abrasion of their teeth in childhood to reduce the cosmetic impact of fluorosis – this could result in lower levels of fluorosis of aesthetic concern in the water fluoridated group. Due to patients moving dentists and the incompleteness of dental records over (in some cases) 30-40 year periods, it was not possible to identify with any degree of confidence whether patients had received cosmetic treatment for fluorosis in childhood.

TABLE 4 n (%) and mean (SD) TF score of age groups

	Age	n (%)	TF Mean (SD)
Fluoridated area	18-22	49 (13.3%)	0.69 (0.77)
	23-27	51 (13.8%)	0.84 (0.99)
	28-32	63 (17.1%)	0.6 (0.87)
	33-37	60 (16.3%)	0.48 (0.79)
	38-42	85 (15.4%)	0.53 (0.83)
	43-47	71 (12.9%)	0.37 (0.70)
	48-52	59 (10.7%)	0.28 (0.51)
Nonfluoridated area	18-22	25 (13.7%)	0.40 (0.76)
	23-27	28 (15.3%)	0.32 (0.72)
	28-32	31 (16.9%)	0.52 (1.15)
	33-37	30 (16.4%)	0.13 (0.35)
	38-42	28 (15.3%)	0.32 (0.61)
	43-47	22 (12.0%)	0.27 (0.88)
	48-52	19 (10.4%)	0.16 (0.50)

TABLE 5 Logistic regression models for dental fluorosis at TF ≥ 1

	B	SE	Wald	Odds ratio	95% CI	*P*
Fluoridated water	0.91	0.21	18.03	2.48	1.63-3.78	<0.01
Age	–0.44	0.01	17.96	0.96	0.94-0.98	<0.01
Sex	0.16	0.19	0.66	1.17	0.80-1.72	0.41
Deprivation	0.04	0.04	0.59	1.04	0.96-1.13	0.37
Ethnicity	0.22	0.31	0.51	1.25	0.68-2.31	0.48

Hosmer & Lemeshow: R^2 = 0.01, $\chi^2(1)$ = 7.049, P = 0.53.
Reference categories: no fluoridation, age 18-22 y, male, most deprived IMD decile and white ethnicity.

A previous study assessed proportions of fluorosis in children living in geographically similar areas and reported that 39% of 12-year-olds in a water fluoridated area presented with no fluorosis (TF = 0).[5] This is lower than the 61% of adults in this study with lifetime exposure who presented with no fluorosis (TF = 0). The Cochrane review of water fluoridation published a table, which estimates the probability of dental fluorosis in children at different fluoride exposures, based on data from 40 included studies.[7] At the 1.0 ppm level, which is the target level for community fluoridation in the UK, the table proposes a 0.15 probability of fluorosis of aesthetic concern, the probability of fluorosis in adults based on data from this study is lower at 0.04. This concurs with the reduction in fluorosis observed in the recent Australian longitudinal study which recruited participants as children and followed them up 10 years later and observed that 55% of participants who originally scored at TF2 and TF3 later scored at TF0 or TF1.[16]

The reasons for the higher proportions of fluorosis in the younger sample are probably multifaceted but one important consideration is the exposure to fluoride from other sources (toothpaste and other prophylactic measures). Such measures are advocated in England's national oral health policy. However, the use of additional fluoride products, such as fluoride varnish, is generally restricted to children over the age of four and hence the risk period for anterior dentition fluorosis has drastically reduced.[31] It is more biologically plausible that, given the superficial nature of the fluorosis lesion, the incremental effects of toothbrush abrasion and erosion from dietary sources accounts for the reduction in the severity of fluorosis over time. Indeed, the use of mild abrasion is frequently used in children to "treat" fluorosis.[32]

Future such research would be beneficial since fluorosis continues to be cited as the main risk of water fluoridation, to confirm whether fluorosis diminishes as children develop into adulthood. To do this ideally, a cohort of people should be followed longitudinally and their all-source exposure to fluoride and any treatment they receive should be recorded. However, such a study design would require long-term follow-up, over more than three decades, presenting a severe logistical challenge and very substantial costs. Comparing the findings of multiple studies of the same population, across a time series is probably a more feasible approach for establishing a body of evidence for the occurrence and impact of fluorosis in adult populations and its relationship with age.

5 | CONCLUSION

In these samples of adult dental patients, there were significantly higher levels of fluorosis in participants with a lifetime exposure to water fluoridation. However, the findings suggest the severity of fluorosis may decrease with age. This may be due to the processes of abrasion (from the tooth brushing and toothpaste) as well as erosion from dietary components.

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CONFLICT OF INTEREST

The other authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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