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Factors associated with surface-level caries incidence in children aged 9 to 13: the Iowa Fluoride Study

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Abstract

Objective—Since dental caries can progress throughout a person's lifetime, understanding caries risk factors unique to specific life phases is important. This study aims to assess caries incidence and risk factors for young adolescents.

Methods—Participants in the longitudinal Iowa Fluoride Study were assessed for dental caries at approximately age 9 and again at age 13. These participants also filled out questionnaires concerning water sources, oral health habits, beverage intakes, parent education and family income. Caries progression ($D_{2+}F$) was analyzed at the surface level. Mixed effects logistic regression was used to assess associations between surface-specific first molar occlusal caries incidence and risk factors.

Results—Caries incidence was quite low except on the first molar occlusal surfaces. In initial models of specific risk factors, incidence was positively associated with the surface having a D_1 lesion at baseline, low family income, having untreated decay or fillings on other teeth at baseline, lower home water fluoride level, and higher soda pop consumption. In the final multiple variable model, significant interactions were found between tooth brushing frequency and initial D_1 status, and also between family income and home tap water fluoride level.

Conclusions— $D_{2+}F$ incidence on first molar occlusal surfaces in these young adolescents was associated with prior caries experience on other teeth as well as prior evidence of a D_1 lesion on the occlusal surface. More frequent tooth brushing was protective of sound surfaces, and fluoride in home tap water was also protective, but significantly more so for adolescents in low income families.

Keywords

dental caries; incidence; adolescents; risk factors

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Introduction

While much attention has been given to dental caries in younger children and the elderly, caries is a chronic disease that affects people throughout life. This study aims to focus on a much-overlooked group, older children and adolescents, with regard to caries epidemiology. While originally more diverse, the Iowa fluoride Study cohort has become less racially diverse (96% non-Hispanic white) and has higher parent educational levels compared to the U.S. population in general. The disease is highly prevalent, even in this more advantaged group, as the most recently published NHANES data (1999–2004) indicated that 31% of 9- to 11-year-olds and 51% of 12- to 15-year-olds had caries experience (1). The NHANES data also shows that non-Hispanic whites had 1–2.5% less incidence at these age ranges, while children in families above 200% of the federal poverty level had approximately 5% less incidence. While the prevalence of permanent dentition caries has declined overall from previous NHANES data (1988–1994), these findings suggest that caries remains very prevalent in the 9- to 13-year age group, even among non-Hispanic whites and mid- to upper- socioeconomic status families (2).

Studies of caries incidence during later childhood and adolescence in the United States and Canada are rare. An early (1988) study of children aged 10–15 years in non-fluoridated Coldwater, Michigan found mean 17-month DMFS increments of 1.14 for pit and fissure surfaces, 0.24 for smooth surfaces, and 1.38 overall. Higher levels of mutans streptococci and lactobacilli were each associated with pit and fissure caries incidence (3). The mean increment varied with age, ranging from 0.78 DMFS among children 10 years old to 1.64 DMFS for those age 15 at baseline (3). More recently (1993–1997), a three-year incidence study among British Columbia children aged 8–9 at baseline (4) found a mean increment of filled surfaces (FS) of 0.42 in a continually fluoridated community compared to 0.89 for children in a community where water fluoridation had ceased. The incidence of untreated decay was negligible, and the number of decayed or filled surfaces (DFS) was not reported.

Several studies of caries incidence in adolescents have been conducted in Scandinavia. One such study reported that mean 2-year caries increment in children aged 12 years at baseline was 1.0 DMFS (5), and that immigrant children, children from working-class families and children living in urban areas were at higher risk for caries incidence. Previous caries experience was also associated with higher rates of caries incidence (5). A follow-up to this study found that the four-year caries increments (age 12 to 16) had increased to an average of 2.07 DMFS. Incidence was associated with socio-economic factors, but was also positively associated with less frequent tooth brushing and more frequent candy consumption (6). A study of 3-year caries incidence in Sweden with 655 children aged 12 at baseline found that past caries experience, along with higher levels of mutans streptococci at baseline, were associated with caries incidence (7). This study found a mean DMFS increment of 1.3 (7). A three-year study of 162 Swedish teen-age girls aged 12 at baseline found that 62% had incident caries (8), which was associated with skipping breakfast, irregular meals and smoking. Frequency of snacking, soft drink consumption and tooth brushing habits were not associated with caries incidence in this study (8). A 6-year longitudinal study in Norway which followed 211 children from ages 10–12 to 16–18 (9) found that increased caries incidence was related to gender (boys > girls), less frequent tooth

brushing with fluoride dentifrice and higher baseline caries experience (9). A study of 181 13-year-old Finnish children assessed 11-month caries incidence and found that DFS increment was associated with baseline caries experience, presence of white-spot lesions, sugar consumption, presence of lactobacilli, and presence of *Candida* (10).

A study in Iceland found 1-year mean caries increment among 11- and 12-year-olds was 2.4 DFS (11). DFS incidence was associated with missing lunch for boys, but not for girls (11). Finally, 206 Brazilian children aged 7 years at baseline were followed in a 7-year caries incidence study which found that greater caries incidence (DMFS>4) was associated with lower maternal education level, lower tooth brushing frequency, and having caries experience in the primary dentition (12).

In summary, a limited number of studies have reported caries incidence among children in later childhood and adolescence and have found caries incidence to be associated with previous caries experience, lower socioeconomic status, increased sugar consumption, and presence of certain microorganisms, including mutans streptococci, lactobacilli and *Candida*. However, most of these studies were conducted outside the United States, and many were conducted 15–20 years ago. Thus, there is a need for a contemporary study of factors related to children in this age group in the United States, as there is virtually no current information regarding dental caries incidence among U.S. or Canadian children at these ages. The purpose of this paper is to report on the incidence of dental caries among the Iowa Fluoride Study cohort children from about age 9 to about age 13 years.

Methods

The Iowa Fluoride Study is an ongoing longitudinal investigation of oral health habits (13, 14), fluoride exposures (15), beverage intakes (16) and dental outcomes (17, 18). Subjects were recruited at birth (1992–1995) among postpartum units at 8 Iowa hospitals and are age 18 to 21 in 2013. While study subjects were initially more diverse, over time the cohort has trended toward being mainly non-Hispanic white (96%) with fairly high income and parent educational levels. Institutional Review Board (IRB) approval was secured for all aspects of the study. Parents provided consent and adolescents provided assent for the dental examinations.

Subjects were from fairly high socio-economic status families, as shown in Table 1. Most subjects (67%) had fluoridated home tap water (0.7 ppm or above) and, on average, subjects brushed their teeth 1.5 times per day. Total fluoride intake (mg/day), as well as intakes (oz./day) of various beverages, are also summarized in Table 1. Use of fluoride mouth rinse varied across time for individual subjects from age 9 to 13, but was used at some point by 38% of the subjects (170 of 443). All subjects used fluoridated dentifrice, although a few used a non-fluoride dentifrice on occasion. No subjects used non-fluoride dentifrice exclusively from age 9 to 13..

The study had 523 subjects who participated in both mixed dentition (approximately age 9) and permanent dentition (approximately age 13) examinations. The dental examinations, by a total of four trained and calibrated dentist examiners, used air to dry the teeth and dental

explorers to remove debris and confirm suspected lesions. Each tooth surface of the permanent teeth (buccal, lingual, mesial, distal, occlusal) was assessed, with separate scores for mesial and distal occlusal pits of the permanent maxillary 1st molars. The criteria distinguished between cavitated (D_{2+}), non-cavitated (D_1) and questionable (D_0) lesions (18). Since radiographs were not used, we did not distinguish between D_2 (enamel) and D_3 (dentin) lesions. We refer to our caries criterion as being either D_2 , D_3 or filled (D_{2+F}). Inter-examiner reliability was assessed using duplicate examinations of 21 subjects at the age 9 exam and 55 subjects at the age 13 exam. Surfaces scored as D_{2+} or filled (D_{2+F}) at the mixed dentition exam (age 9, 1.1%) were excluded from these analyses, since transitions on those surfaces were not always detectable (e.g., if a filling later had recurrent decay and was re-filled during the 4-year interval). Thus, reversals (D_{2+} /filled surfaces at age 9 that were recorded as sound at age 13) have been ignored since all surfaces with initial D_{2+F} scoring were excluded. Surfaces which had not yet erupted (1.9%) or already had sealants (6.5%) at age 9 were also excluded from these analyses. Surface-level caries incidence was defined as any surface-level progression from sound, D_0 or D_1 at age 9 to D_{2+} or filled (or both) at age 13. Mixed dentition weighted kappa for surface-level scoring (sound, D_1 or D_{2+F}) was 0.55, and permanent dentition weighted kappa was 0.66, showing good reliability between the dentist examiners.

This study presents findings for the permanent incisors and 1st molars only, since other permanent teeth mostly were not yet erupted at the age 9 exam and exposure to risk factors varied with time of eruption, which was not documented. While caries experience on primary teeth has been shown to be a valid predictor of permanent tooth caries, we decided instead to use age 9 D_2F presence (permanent teeth) as a predictor for incidence since it gives a more current estimate of the disease state within subjects.

Risk factor data were obtained by periodic questionnaires which were mailed twice per year to study participants. The questionnaires assessed water sources, beverage and selected food intakes, tooth brushing frequency, use of fluoridated dentifrice and fluoride supplements, and were also used to estimate the amount of fluoride ingested from dentifrice. Water sources were linked to municipally-reported fluoride levels or assayed for fluoride content (non-municipal and filtered water). Total fluoride intake (mg) was estimated from amounts of beverages consumed (including water), foods with substantial amounts of added water, fluoride supplements and ingested dentifrice. Area-under-the-curve (AUC) estimates were obtained for each covariate in the questionnaires from age 9 to 13 using the trapezoidal method. AUC estimates were divided by time interval, so that each continuously-scaled AUC variable represents a weighted average from age 9 to 13, and the AUC for the fluoride mouthrinse (dichotomous) represents an estimate of the proportion of time that mouthrinse was used. For the present study, 80 subjects were excluded due to inadequate responses for water fluoride levels, tooth brushing frequency or beverage intake estimates, resulting in a sample of 443 subjects. There were no significant differences between the 80 dropped subjects with respect to mother's education, family income, or levels of caries at age 9 or 13 (all $p > 0.23$). Parental education and family income levels were assessed in 2007 (when participants were approximately age 12 to 14) using a separate mailing. Permanent tooth $D_{2+FS} > 0$ at the age 9 exam was also used as a risk factor.

All data were analyzed using SAS (9.2). Caries scores for the two dental exams were matched at the tooth surface level. Caries incidence of incisors and 1st molar smooth surfaces was quite low, so only summary tabulations are presented. Incidence on 1st molar occlusal surfaces was sufficient to allow mixed effects regression modeling. Since ages of subjects at both initial and follow-up examinations were quite similar (mostly age 9 and 13), we used logistic regression rather than proportional hazard regression. Specifically, generalized linear mixed models (SAS GLIMMIX procedure) based on a Bernoulli distribution and a logit link function were fit using a quasi-likelihood approach. Multiple tooth surface outcomes for subjects were treated as repeated measurements, and the subject-level clustering was accommodated in the computation of classical sandwich-based standard errors. In order to get a clear comparison of surfaces that were initially sound vs. D₁, the small number of 1st molar occlusal surfaces scored as D₀ at the age 9 exam were excluded from occlusal surface analyses (n=28). Tooth surface status at the age 9 exam (D₁ vs. sound) was used as a covariate in all occlusal incidence models. Screening (mixed effects logistic) regressions were used to select independent variables that had borderline (p = 0.10) association with occlusal incidence (after adjusting for D₁ status), and only those variables were considered for the multiple regression model. Backward elimination was used to find variables that were all jointly significant (p = 0.05). Two-way interactions between main effects in the multiple regression model were also tested.

Results

The subjects in the study (n=443) were predominantly white (96%), with 51% female and 49% male. Mothers were well educated, with 49% having a 4-year college degree, and only 13% of families reporting an income under \$40,000 per year in 2007. As seen in Table 2, subject-level permanent tooth D₂₊F prevalence and age 9–13 incidence (1.6%) was quite low for incisors, and was also moderately low for 1st molars (16.9% incidence). Most surfaces with caries incidence were filled (85%) rather than frank caries (D₂₊, 15%).

Subject-level D₂₊F incidence was quite low for incisors (1.6%), but substantially higher for 1st molars (16.9%). Surface-level D₂₊F incidence by tooth type, surface type and arch is presented in Table 3. Smooth surface-level incidence was extremely low (0 to 1.1%), as was incidence for mandibular buccal and maxillary lingual surfaces (1.8% and 3.4%, respectively). Incidence on 1st molar occlusal pits was more substantial (6.7% mandibular, 6.1% maxillary).

D₂₊F incidence on 1st molar occlusal surfaces was analyzed further using mixed effects logistic regression models to screen for individual associations, but each screening regression also adjusted for initial caries score at the surface level (D₁ vs. sound). Odds ratios, 95% confidence intervals (C.I.) and p-values are presented in Table 4. Covariates with at least borderline significance (p<0.10) were considered for the multiple variable regression model.

Screened variables that were not statistically significant (had p > 0.05) in the multiple variable regression model were dropped through backward elimination, retaining only variables that were jointly significant. Only soda pop consumption was dropped using this

method. Soda pop had a large negative correlation ($r = -0.20$, $p < 0.001$) with tooth brushing frequency, which prevented both tooth brushing frequency and soda pop from being jointly significant in the multivariable caries model. Next, 2-way interactions between the main effects were tested singly, retaining only those that were statistically significant. The resulting model (Table 5) shows that subjects with $D_{2+}F$ on other permanent teeth at age 9 had significantly higher rates of $D_{2+}F$ incidence, as did subjects in low income families and subjects that brushed less frequently. Other significant effects were the age 9 D_1 by brushing frequency interaction and the low income by water fluoride level interaction.

The effect of brushing frequency, which is moderated by the status of the tooth surface at age 9 (D_1 vs. sound), is presented in Figure 1. While estimated $D_{2+}F$ incidence increased with brushing frequency for surfaces with D_1 lesions, the regression coefficient had a large standard error and was not statistically significant ($p = 0.14$). However, the p-value for decreasing incidence on sound surfaces was both stable and statistically significant ($p = 0.006$). Therefore, the significant interaction seen between brushing frequency and D_1 status ($p = 0.009$) is likely due to the preventive effect of brushing frequency for sound surfaces which is not evident for D_1 surfaces. For surfaces that were initially sound (94% of surfaces), estimated caries incidence for subjects brushing only once per day was 4.5% vs. 1.3% incidence for subjects brushing twice per day.

The effect of home tap water fluoride level, which is moderated by income level, is presented in Figure 2. While estimated caries incidence decreased with higher fluoride levels in home tap water, the effect was much more pronounced in families with lower income. For subjects in families with lower income, estimated caries incidence at home fluoride levels of 0.5 ppm was 10.2% vs. 2.2% incidence at fluoride levels of 1.0 ppm. However, for subjects in families with moderate or higher income, estimated caries incidence at home fluoride levels of 0.5 ppm was 3.7% vs. 2.2% incidence at fluoride levels of 1.0 ppm. It is important to note that both Figure 1 and Figure 2 represent only cross sections of the logistic regression response surface, where all other effects have been set to their median value.

Discussion

Disease rates in this study were relatively low, as might be expected in non-Hispanic white populations with relatively well-educated parents. $D_{2+}F$ prevalence in the cohort was only 22% at age 9 and 26% at age 13. This is much lower than the NHANES data for 1999–2004 which show prevalence of 26–30% for 9-to 11-year-olds and 46–50% for 12- to 15-year olds that are non-Hispanic white and/or 200% or more above the federal poverty level. Incidence on smooth surfaces in this study was extremely low (0.3%), with most incidence being found on the occlusal surfaces of the 1st molars (6% incidence). Most incidence was from fillings (85%), rather than frank decay (15%), which may be attributable in part to dentists' treatment choices. Total four-year incidence in this study was also low (18%), with mean $D_{2+}FS$ increment of 0.36. This is well below the 17-month increment of 1.38 DMFS reported in Coldwater, Michigan (3), possibly due to the majority of our subjects having fluoridated water. It is also below the 3-year increment in British Columbia (5) of 0.42 FS per subject, even though that community was fluoridated. The studies in Scandinavia (6–11) and Iceland (12) also had higher incidence than our study. However, even with low

incidence, there were significant effects on D₂₊F caries incidence on 1st molar occlusal surfaces for tooth brushing frequency, family income level, water fluoride level and previous caries experience. It is hoped that future studies in more caries-prone populations will corroborate these effects.

Initial screening regressions found significant relationships between 1st molar occlusal caries incidence and family income, previous caries experience (on other teeth), the age 9 status of the occlusal surface (D₁ vs. sound), fluoride level of home tap water, and soda pop consumption (oz./day). No other dietary variables were significantly related to caries incidence. Use of fluoride mouth rinse was also not significantly related to caries incidence, although we have noticed that subjects with caries are more likely to begin using fluoridated mouth rinse. Validation of the efficacy of fluoride mouthrinse should be sought in clinical trials rather than observational studies such as this one.

In the final multiple variable regression model, the small number of initial D₁ lesions was likely a contributing factor in the positive effect on caries incidence for brushing frequency of surfaces with initial D₁ lesions. The positive estimate may also be due to dentists' treatment of D₁ lesions in conjunction with an emphasis on better decay prevention habits. However, the main significance of the D₁ lesion by brushing frequency interaction (Figure 1) is found in the preventive properties of tooth brushing on sound surfaces that is not evident for D₁ surfaces.

The final multiple variable regression model also confirms the caries-preventive effect of fluoride in home tap water sources. While this effect is present for all subjects, it is most pronounced in subjects with lower family income.

This study had several limitations. Analysis of factors associated with caries was limited to caries incidence on 1st molar occlusal surfaces, and those same associations may not apply to other teeth or smooth surfaces in general. Surfaces with sealants at age 9 were excluded, as were surfaces with an initial assessment of "questionable" caries. We think that this has made the associations cleaner, but it also has made the sample size of tooth surfaces smaller. The 443 subjects in the study are long-time participants in the Iowa Fluoride Study, and are more socioeconomically advantaged than the general population and Iowa Fluoride Study recruits who have dropped out. They are not representative of the U.S. population in general, and conclusions should not be generalized to other populations. More studies are needed to validate the associations found here using populations that are more diverse and have caries rates that are more representative of the United States population.

Conclusions

When assessing age 9 to 13 caries incidence on 1st molar occlusal surfaces, prior caries experience was an important risk indicator. More frequent tooth brushing was effective at protecting sound surfaces from new caries, and home tap water fluoride level was also protective, but significantly more so for low income families.

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Figure 1.

Estimated $D_{2+}F$ caries incidence* of occlusal pits/fissures by initial status and brushing frequency

* See Table 5 for source model. All effects not plotted have been set to their median values.

Figure 2.

Estimated D₂+F caries incidence* of occlusal pits/fissures by income and fluoride levels*

* See Table 5 for source model. All effects not plotted have been set to their median values.

Table 1

Summary of Covariate Measures.

		Percentage (N=443 subjects)
Mother's Education:	Unknown	3%
4-year college degree	No	48%
(2007)	Yes	49%
Family Income	Unknown	5%
(2007)	<\$40,000	13%
	\$40,000 or more	82%
Age 9 D ₂₊ F > 0	No	78%
	Yes	22%
Age 9 D ₁ (surface level)	No	94%
	Yes	6%
	Mean (Std.Dev.)	Median (Range)
Age Interval (years)	4.2 (0.8)	4.2 (1.3 – 6.9)
<u>AUC age 9–13:</u>		
Total mgF/day	0.73 (0.35)	0.65 (0.18 – 2.04)
Brushing frequency/day	1.5 (0.5)	1.7 (0.5 – 2.9)
Home water F (ppm)	0.82 (0.44)	0.97 (0.03 – 5.41)
Water oz./day	12.8 (8.4)	10.9 (0 – 56.2)
Milk oz./day	12.2 (6.6)	11.7 (0 – 41.2)
100% juice oz./day	2.3 (2.5)	1.6 (0 – 16.9)
Juice drink oz./day	2.0 (2.2)	1.3 (0 – 17.7)
Powdered beverage oz./day	1.9 (3.0)	0.9 (0 – 37.8)
Low calorie beverage oz./day	1.7 (3.0)	0.4 (0 – 29.6)
Soda pop oz./day	3.8 (3.7)	2.9 (0 – 38.9)
Sport drink oz./day	1.7 (2.7)	0.7 (0 – 32.5)
Fluoride mouth rinse (proportion of time used)	0.14 (0.25)	0.0 (0.0 – 1.0)

Table 2

Person-level Prevalence/Incidence Summary

Tooth Type	Prevalence (Mean D ₂₊ FS)		Incidence (Mean D ₂₊ FS)
	Age 9	Age 13	Age 9 – 13
Incisors	0.5% (0.01)	1.8% (0.03)	1.6% (0.03)
1 st Molars	21.9% (0.54)	25.5% (0.69)	16.9% (0.34)
Combined	21.9% (0.54)	26.4% (0.72)	18.1% (0.36)

Table 3Summary of Surface-level D₂+F Transitions

Tooth Type	Surface	Arch	Max. Surfaces Per Subject	Excluded due to Age 9:			Remaining Number of Surfaces*	D ₂ +F Incidence
				Not erupted	D ₂ +F	Sealant		
Incisor	Buccal, Lingual, Mesial, Distal	Mandibular	16	108	0	0	6948	0.0%
	Buccal, Lingual, Mesial, Distal	Maxillary	16	208	4	0	6816	0.2%
1 st Molar	Lingual, Mesial, Distal	Mandibular	6	24	5	1	2574	0.5%
	Buccal	Mandibular	2	8	42	75	741	1.8%
	Occlusal pits/fissures	Mandibular	2	1	53	484	345	6.7%
	Buccal, Mesial, Distal	Maxillary	6	72	7	4	2485	1.1%
	Lingual	Maxillary	2	24	34	118	681	3.4%
	Occlusal pits/fissures	Maxillary	4	4	104	852	807	6.1%

* Omits surfaces which, at age 9, were not erupted, had sealant or D₂+F.

Table 4

Logistic Screening Regression Summary of Covariate Measures and Relationships with 1st Molar Occlusal Caries Incidence ($D_{2+}FS > 0$).

	Screening Regressions* (N=1,128 surfaces)	
	Odds Ratio (95% C.I.)	p-value
Mother's Education (2007): 4-year college degree	0.70 (0.35,1.40)	0.31
Family Income (2007) <\$40,000	2.18 (1.01,4.68)	0.05
Age 9 $D_{2+}FS > 0$	3.10 (1.55,6.20)	0.002
Age 9 D_1 (surface level)	6.09 (3.12,11.88)	<0.001
Age Interval (years)	1.14 (0.80,1.63)	0.47
AUC age 9–13:		
Total mgF/day	1.39 (0.56,3.41)	0.48
Brushing frequency/day	0.50 (0.23,1.08)	0.08
Home water F (ppm)	0.22 (0.09,0.54)	0.002
Water oz./day	1.02 (0.98,1.06)	0.34
Milk oz./day	0.97 (0.92,1.02)	0.18
100% juice oz./day	0.96 (0.81,1.15)	0.67
Juice drink oz./day	0.98 (0.87,1.10)	0.70
Powdered beverage oz./day	1.03 (0.97,1.08)	0.36
Low calorie beverage oz./day	1.00 (0.90,1.11)	0.99
Soda pop oz./day	1.11 (1.00,1.23)	0.05
Sport drink oz./day	1.04 (0.97,1.12)	0.31
Fluoride mouth rinse (proportion of time used)	0.92 (0.27,3.20)	0.90

* All screening regressions are adjusted for Age 9 D_1 at the surface level.

Table 5

Mixed Effects Logistic Regression Model for Surface-level D₂₊F Transitions on First Molar Occlusal Surfaces.

Effect	Odds Ratio (95% C.I.)	p-value
Intercept	0.48 (0.10,2.28)	0.36
D ₂₊ FS>0 at age 9 exam (vs. none)	3.26 (1.58,6.72)	0.002
D ₁ score at age 9 (vs. sound)	0.14 (0.007,2.65)	0.19
Brushing frequency (AUC, age 9–13)	0.28 (0.12,0.69)	0.006
D ₁ * brushing frequency interaction	10.93 (1.85,64.49)	0.009
Home tap water fluoride level (ppm)	0.32 (0.10,1.02)	0.056
Low income (<\$40,000 annually)	8.24 (2.34,29.04)	0.002
Low income * fluoride level interaction	0.13 (0.02,0.79)	0.03