Estimating Fluoride Exposure in Rural Communities: A Case Study in Western Washington

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Purpose: Efforts to achieve national objectives for fluoridation, such as Healthy People 2010, and water quality monitoring regulations focus on public water systems and generally overlook the 15% of U.S. households with private wells. Mandated testing of public water systems and new building sites on San Juan Island, Washington revealed naturally occurring fluoride levels up to several times the EPA Maximum Contaminant Level. This study evaluated fluoride concentrations in private wells and estimated the prevalence of dental fluorosis among children to inform local stakeholders.

Methods: Primary school children were examined by a dentist for dental fluorosis, parents were surveyed about fluoride exposures, and household drinking water samples were collected to measure and map fluoride concentrations. De-identified data were analyzed using chi-square and Fisher's exact tests.

Results: 18.8% of examined children exhibited mild dental fluorosis, a prevalence similar to national averages. Fluoride concentrations in drinking water were 0.08 to 1.30 mg/L, below levels for health concerns, and generally (94%) below levels recommended for caries prevention. Supplemental sources of fluoride (e.g. tablets) did not account for observed fluorosis.

Conclusion: Results provided community stakeholders with valuable information to support decision-making regarding fluoride levels in drinking water. Previously available information suggested potential for excessive fluoride exposure, however, these study results indicated low fluoride levels were more common. The approach used in this case study suggests a simple method of assessing the scope of fluoridation needs in communities where private water sources are common, allowing for better informed decision-making with regard to future fluoridation efforts.

Introduction and Review of Literature

In the last 50 years, the incidence of dental caries has declined precipitously in the United States, a health advance that most scientists attribute to increased access to fluoridated water and dental products. Dean and colleagues in the 1930's revealed an inverse association between the presence of fluoride at low levels in the water supply and reduced prevalence of dental caries (Dean, 2006). Based on these findings and subsequent research, the United States Public Health Service recommends that community drinking water should contain 0.7 to 1.2 milligrams per liter (mg/L) of fluoride for caries prevention (U.S. Centers for Disease Control and Prevention, 2001). One goal of Healthy People 2010 is, "Increase the proportion of the U.S.

population served by community water systems with optimally fluoridated water," with a target of 75% by 2010 (U.S. Department of Health and Human Services, 2000). As of 2006, this goal had been achieved for nearly 70% of residents connected to a community water system, although the percentage varied widely between states (U.S. Centers for Disease Control and Prevention, 2008). These national objectives, however, focus on public water systems and overlook approximately 15 percent of American households where drinking water is obtained from private, individual wells (U.S. Census Bureau, 1990).

In addition to community water fluoridation, fluoride can occur naturally in groundwater, depending on the underlying geologic structures. In regions where fluoride occurs naturally, the U.S. Environmental Protection Agency (EPA) specifies a maximum level of fluoride in drinking water at 4.0 mg/L, the EPA Maximum Contaminant Level (MCL), chosen to prevent possible skeletal fluorosis (U.S. Environmental Protection Agency, 2006b). A secondary MCL of 2.0 mg/L is recommended to minimize the “cosmetic” risk of dental fluorosis, which can occur when fluoride is incorporated into enamel during tooth development. Depending on the amount of fluoride exposure and timing relative to tooth development, severity of dental fluorosis, though mainly aesthetic, can range from barely discernible to manifestations of stained and pitted tooth enamel (National Research Council, Subcommittee on Health Effects of Ingested Fluoride, 1993).

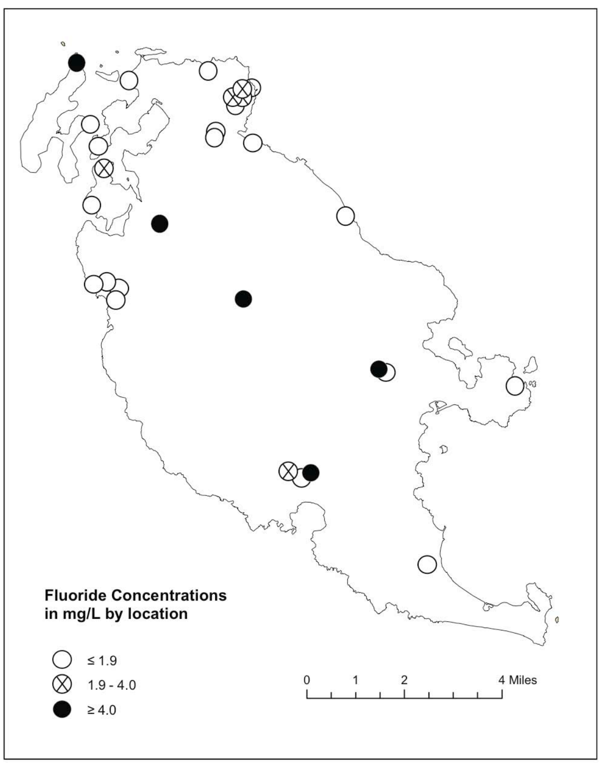
The prevalence of dental fluorosis in the U.S. is reported to range from 35 to 60 percent in communities with regulated public water systems and fluoridation, compared with 20 to 45 percent in communities without fluoridation (Clark, 1994). In 1999-2002, the National Health and Nutrition Examination Surveys (NHANES) found very mild or greater enamel fluorosis in 23% of the surveyed population (ages 6-39) (U.S. Centers for Disease Control and Prevention, 2005). The prevalence and severity of dental fluorosis have increased since initial recordings by Dean and colleagues in 1945 (Clark, 1994; U.S. Centers for Disease Control and Prevention, 2005). Additional elective fluoride exposure can occur through prescriptive treatments from a dentist or health care provider (e.g. fluoride varnish, rinses, or tablets). Other sources of fluoride may be through baby formulas, soft drinks, and other consumables. Recent studies indicate a greater contribution to risk of fluorosis from drinking water than elective fluoride sources, contrary to what was previously thought (Spencer & Do, 2008; Lewis & Banting, 1994).

Regardless of the source, there remains a need for studies of the prevalence and severity of dental fluorosis in U.S. communities with fluoride concentrations greater than 1 mg/L (National Research Council Committee on Fluoride in Drinking Water, 2006). It may be particularly important to focus public health investigative efforts on the 15 percent of American households that are served by private, individual wells, and that often are not monitored or formally regulated by local or state government.

Case study. The present investigation was prompted by community concerns about naturally occurring fluoride in drinking water on San Juan Island in Washington State. Island residents are served either by unfluoridated municipal water, distributed through a public system to approximately 2,000 people in the city of Friday Harbor, or by individual public or private wells, serving approximately 5,000 people. Routine water quality testing, including fluoride, is required for shared well-water systems. Private well-water systems are not systematic tested, other than San Juan County-mandated testing for all new building sites. In 2004, a County report summarized water test results for 122 wells evaluated during [1996-2003], revealing fluoride levels of 0.51-12.45 mg/L, including six sites with levels several times the EPA MCL (Figure 1) (San Juan County Water Resource Management Committee, 2004). The report generated community concern about possible excessive fluoride exposures for children throughout the island. The County Department of Heath and Community Services asked the University of Washington (UW) to conduct a collaborative study with the County and local school district to investigate fluoride issues.

This investigation sought to reach a broad sample of Island households served by private individual wells, in order to assess fluoride concentrations in drinking water and the prevalence of dental fluorosis among children. This study illustrates a practical strategy by which a small community can investigate fluoride exposure, particularly in households obtaining drinking water from otherwise non-monitored wells.

Figure 1. Fluoride concentration levels on San Juan Island as recorded by the San Juan County Water Resource Management Committee. Several locations exceed the EPA- recommended maximum contaminant level (4 mg/L), which was the motivation to pursue this project.



Methods

This study used a cross-sectional study design with three components: dental fluorosis screening of young children at an elementary school, a household questionnaire, and fluoride analysis of household tap water. The San Juan County Department of Heath and Community Services and the Friday Harbor School District collaborated in each stage of planning and implementation. The study was approved by the UW Institutional Review Committee and the Friday Harbor School Board. Parents provided written informed consent for child and parent participation. Children provided verbal assent at the fluorosis screening. All study materials were anonymized and tracked using identification codes.

Participation was sought from all children (n=118) in grades 2 or 3 in the Friday Harbor School District, the only public elementary school on San Juan Island. A short educational lesson and discussion about the study were held in each classroom (six total). Classroom teachers distributed and collected permission slips and questionnaires to be completed by parents.

Procedures

The presence and severity of dental fluorosis were assessed using the Thylstrup and Fejerskov Index (TFI), widely considered a "near ideal instrument" that is more sensitive than others in communities with minor to moderate dental fluorosis (Thylstrup & Fejerskov, 1978; Mabelya, van't Hoft, König, & van Palenstein Helderman, 1994). The TFI is measured in ten categorical increments of severity from 0 to 9; dental fluorosis is present at values greater than or equal to 1. A recently developed visual analog scale (VAS) was also used in the assessments. The VAS includes standardized photographs to calibrate the examiner and a 0-100 linear scale (Vieira, Lawrence, Limeback, Sampaio, & Grynpas, 2005). Assessments were conducted by a dentist (PM).

Children were asked to smile and show the dentist their teeth. The labial surfaces of central and lateral incisors were examined under ambient light. If children were missing any of these teeth, only the present teeth were examined.

The household questionnaire was completed by a parent, providing information about demographic features, address, water supply (nature, source, and filtration), the child's dental habits including details of fluoride exposure, and use of dental services. Parents were asked to collect a sample of household tap water (50 mL poly Nalgene container provided), and return it to school with the questionnaire.

Fluoride content of tap water was measured at the UW Analytical Service Center laboratory, in accordance with the EPA Methods of Chemical Analysis of Water and Wastes Method 300 for fluoride concentration, against known standards (U.S. Environmental Protection Agency, Environmental Monitoring Laboratory, 1983). Fluoride levels in drinking water samples were compared to EPA and CDC guidelines.

Data Analysis

Data were analyzed using Stata for Mac (StataCorp. College Station, TX, 2007). Descriptive statistics of demographic variables were compared to 2002 U.S. Census data for San Juan Island. To characterize prevalence of dental fluorosis, TFI and VAS scores were dichotomized (0 versus ≥1 for TFI, <5mm, ≥5mm for VAS). Fisher's exact probability test was used to determine the correlation between the two fluorosis measures. Associations between dental fluorosis and fluoride exposure were assessed with Pearson chi-square or Fisher's exact tests, evaluated at the level of significance at α=.05.

Mapping Fluoride Levels

Home addresses from questionnaires were converted to global positioning system coordinates using GPS Visualizer (http://www.gpsvisualizer.com). Fluoride levels in household water samples were paired with GPS coordinates and mapped using ArcGIS, Version 9.2 (Environmental Systems Research Institute, Redlands, CA, 1999-2006).

Results

Demographic Characteristics

Self-reported characteristics of participating households were similar to San Juan Island residents overall (Table 1) (U.S. Census Bureau, 2002). Approximately half (53%) of the 118 eligible 2nd and 3rd grade students completed all three components of the study. Some participants did not complete all components of the study. Completion of each component was: household questionnaire, 70% (n=83); child dental fluorosis exam, 54% (n=64); household water sample, 73% (n=87).

Water Fluoride Content

Analysis of water samples was limited to those with accompanying addresses (N=83) and revealed relatively low concentrations of fluoride, ranging from 0.08 to 1.30 mg/L. Nearly all (93.8%) of the levels were below the minimum level recommended by the U.S. Public Health Service for caries prevention (0.7 mg/L), 2.5% fell within the recommended range (0.7-1.2 mg/L), and 3.8% were above this range.Error! Bookmark not defined. All levels were below the EPA MCL (4 mg/L) and secondary MCL (2 mg/L).

Fluorosis Screening

Examinations revealed low prevalence of dental fluorosis in the study sample. Based on the TFI, only 12 (18.8%) children had fluorosis (TFI ≥1). The highest observed TFI value was 3. VAS and TFI scores were highly correlated, (Fisher's exact test, $p < 0.000$); for the analysis, the more standardized TFI scores were used.

Fluoride Exposures

Table 2 summarizes fluoride exposures relative to the presence or absence of dental fluorosis. Over

Table 1. Demographic characteristics of questionnaire respondents.

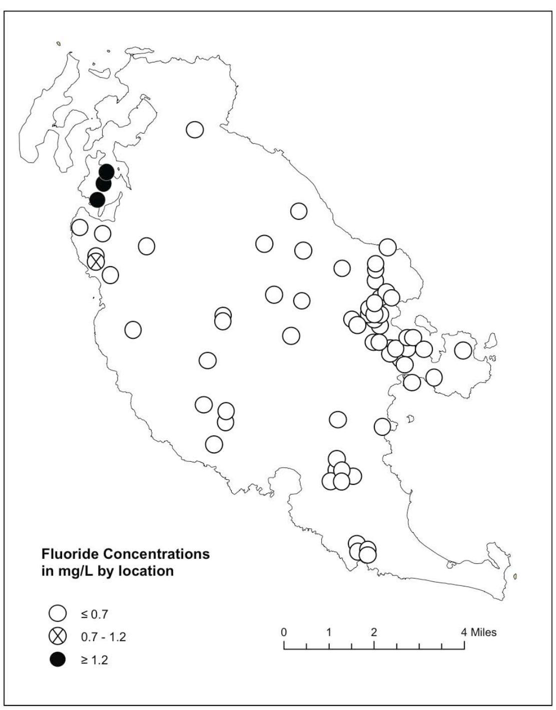
Variable*	Respondents (n = 83)**		San Juan Island (Population 6,984)***
Age (Mean and SD)			46.5
Child	8.0 (1.0)		
Parent	39.7 (7.4)		
Sex (male, number and %)			3,387 (48.5)
Child	32 (40)		
Parent	23 (29.1)		
Parent Ethnicity (%)			
White	75 (74.9)		6,642 (95.1)
Black	0		21 (0.3)
Asian	1 (1.3)		63 (0.9)
Hispanic and other	3 (3.8)		258 (3.7)
Income (%)		**Income (%)*** **	
≤$20,000	5 (6.5)	≤$14,999	957 (13.7)
$20,001-40,000	13 (16.9)	$15,000-39,999	1,579 (22.6)
$40,001-60,000	22 (28.6)	$35,000-49,999	1,530 (21.9)
$60,001-80,000	20 (26.0)	$50,000-74,999	1,369 (19.6)
$80,001-100,000	6 (7.8)	$75,000-99,999	580 (8.3)
>$100,000	11 (14.3)	>$100,000	971 (13.9)
Education of parent who filled out questionnaire (%)			
Less than high school	2 (2.5)		489 (7.0)
High school diploma	14 (17.7)		1,515 (21.7)
Some college or 2-year degree	29 (36.7)		2,444 (35.0)
4-year college degree or higher	34 (43.0)		2,528 (36.2)

* Values represent mean (and standard deviation) or counts (and percent in parentheses).
** Counts may not sum to total, due to non-response; percentages are calculated based on counts listed for each variable.
*** Source: U.S. Census Bureau, (2002). Note, income categories used for the survey were similar but not identical to those used by the Census.

Table 2. Supplemental sources of fluoride, child brushing behavior and drinking water fluoride levels among children with or without dental fluorosis.

	Children with completed questionnaire	Children who also had fluorosis screening		
	(n=82)	All teeth TFI=0 (n=52)	Any tooth TFI≥1 (n = 12)	P-value **
More than 1 source of fluoride supplement	47 (57.3)	26 (50)	8 (66.7)	0.35
Child uses fluoridated toothpaste	37 (48.1)	26 (53.1)	3 (27.3)	0.18
Child observed eating or licking toothpaste	17 (26.6)	15 (28.9)	2 (16.7)	0.49
Drinking water fluoride level				
Below PHS guideline (<0.7 mg/L)	75 (93.8)	48 (92.3)	11 (100)	0.60
Within PHS guideline (0.7-1.2 mg/L)	2 (2.5)	1 (2.0)	0	
Above PHS guideline (>1.2 mg/L)	3 (3.8)	3 (5.9)	0	

* Values represent the number of children, with percentage given in parentheses. Counts may not sum to totals, due to non-response and/or water samples not returned for analysis. Percentages are calculated based on counts listed for each variable. TFI = Thylstrup and Fejerskov Index
** Pearson chi-square or Fisher's exact tests for significance.



half of children had been exposed to one or more supplemental source of fluoride (e.g., fluoride toothpaste, tablets, drops, mouthwash, or varnish), particularly using, eating or licking fluoridated toothpaste. There were no significant associations between dental fluorosis and exposure to fluoride in household water or fluoride supplements.

Mapping Fluoride Levels

Spatial mapping of household water fluoride levels showed that most samples came from households in Friday Harbor, the most densely populated area on the island, and along the west coast of the island (Figure 2). The samples collected for this study included many areas of San Juan Island that were not encompassed by the 2004 County report. A clustering of fluoride levels above 1.2 mg/L in the island's northwest region corresponded with the region where the county previously found three water samples with fluoride levels above 4 mg/L.

Discussion

This study found that drinking water fluoride levels in this geographically isolated community rarely exceeded and were generally lower than the range recommended by the U.S. Public Health Service and were well below EPA limits. This was consistent with the observed low prevalence of dental fluorosis in school children. These results, albeit negative in the scientific sense, provided important information to address community concerns stimulated by a 2004 report that uncovered instances of extremely high fluoride levels in this community.

Dental fluorosis screening in this community revealed a prevalence of fluorosis that was similar to national data (U.S. Centers for Disease Control and Prevention, 2005). Neither drinking water nor supplemental sources of fluoride accounted for the small number of detected children with dental fluorosis. This study did not ascertain exposure to fluoride in purchased soft drinks, foods, and water, but these other sources are unlikely to be significant contributors given that the overall prevalence of fluorosis was very low. Parents, dentists, physicians, teachers and other members of this community found this information reassuring.

This study is distinctive in that the effort was community-driven, used readily available resources, and provided timely information about the population of greatest concern in this situation, young children. Based on a previous County report of fluoride levels identified during mandated testing of public water systems and new building sites, the County was prepared to undertake potentially costly efforts to reduce residents' exposures to fluoride. The additional information from the present study enabled local agencies and community members to make better informed policy decisions.

The observed discrepancy between the data from public wells monitored routinely by San Juan County and the private well data collected in the present school-based study may simply reflect differences in sampling locations. Spatial mapping demonstrated that the present study, like the previous report, did not include all inhabited areas of the island. However, together, the two sources of information, particularly the geographic mapping, provided a more complete assessment of the community as well as guidance for future monitoring and evaluation.

Recent reports have shown considerable progress toward the Health People 2010 objective to increase the proportion of the U.S. population served by community water systems who receive optimally fluoridated water to 75% (U.S. Centers for Disease Control and Prevention, 2001). However, the 15% of American households that obtain drinking water from non-public water systems are effectively excluded from these public health goals and interventions (U.S. Census Bureau, 1990), because they generally are not subject to routine monitoring. The approach used in this study demonstrates a simple method for assessing fluoridation needs in communities where private water sources are common, such as San Juan Island.

Public discourse regarding fluoridation of public water supplies is increasingly common in Washington and throughout the United States. In Bellingham, a large city near San Juan Island, voters have twice rejected initiatives promoting fluoridation of municipal water supplies despite significant expenditure of effort and funds to educate and involve the public (Roosevelt, 2005). Broader understanding of the baseline prevalence of fluorosis in communities with high or low levels of fluoride in the water, whether naturally or artificially occurring, can better inform policy makers and health care providers as they address this important health issue. Small communities can independently estimate the levels of fluoride and other contributory sources in their community through a simple process like that illustrated in this study.

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