Problems in Exposure Assessment of Fluoride in Drinking Water

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Abstract

Objectives: *We developed a source documentation approach that identified fluoride content of drinking water at the state or local level to estimate fluoride concentrations from public water systems. We then compared estimates from this approach with estimates obtained from a single source, the 1992 Centers for Disease Control and Prevention (CDC) Fluoridation Census.* ***Methods:*** *We used residential histories from a case-control study. For each residence we attempted to determine fluoride concentrations using the 1992 CDC Fluoridation Census. For the source documentation method we utilized multiple sources from state and local contacts to verify and collect additional data. We compared the fluoride estimates obtained by the two methods.* ***Results:*** *When fluoride values were found using both methods, there was good correlation (Kendall's tau=0.85; 95% confidence interval=0.79, 0.90) and concordance was 96 percent. We obtained over 99 percent of the fluoride values needed using source documentation as compared to 49 percent of the values needed when we used a single publication. When fluoride values were missing using the 1992 CDC Fluoridation Census, 21 percent had source documentation estimates of at least 0.7 ppm.* ***Conclusions:*** *Researchers need to consider limitations of using a secondary data source to estimate fluoride in drinking water, particularly in studies where exposure to fluoride is the primary exposure of interest. [J Public Health Dent 2004;64(1):45-49]*

Key Words: water supply, fluorides, fluoridation, epidemiology, environmental exposure.

Researchers are actively studying the effects of fluoride exposures on various health outcomes. This paper describes problems in assessing fluoride concentration in drinking water using available national or state publications and explores methods to reduce error for estimating lifetime fluoride exposure for subjects who use public water systems.

The Centers for Disease Control and Prevention (CDC) collects data on fluoride concentration in water systems, aggregates the data at the state and national level, and has published a fluoridation census. State participation is voluntary and the CDC does not confirm the accuracy of the data collected. The census was designed as a surveillance tool to monitor the population receiving fluoride in public drinking water, not as a research tool to obtain actual fluoride levels at a specific residence. Therefore, investigators using the census to obtain source data for case-control studies need to be aware of some intrinsic limitations. The 1992 CDC Fluoridation Census (1) only reported information for water systems that were close to or above the optimal range for dental caries reduction, generally between 0.7 and 1.2 parts per million (ppm) based on climate; therefore, many water systems were not included. Furthermore, once a water system adjusts the concentration of fluoride, information about the natural level prior to adjustment is not published. In this study, we compared the fluoride levels estimated from a single source, the 1992 CDC Fluoridation Census, to those estimated using a more complex method of source documentation to ascertain the value of this more labor-intensive approach.

Methods

Source of Data. We sought to estimate lifetime fluoride exposure for subjects in a national case-control study (2). A complete lifetime residential history was obtained by telephone interview and a separate record was created for each address. Information collected for each residence included the primary type of the subject's drinking water (municipal, private well, bottled) and the subject's age(s) while at that address. We determined the specific year(s) the subject lived at each address. Data on a total of 471 subjects were available based on preliminary eligibility criteria for the case-control study, a completed interview including residential histories, and use of municipal water as their primary source of drinking water for at least one residence.

We generated a list of all communities (cities and towns) in which subjects lived, sorted by state. The 471 subjects used municipal water at 1,264 different residences located in 824 distinct communities. Organizing the information from the residences into distinct communities has three methodologic advantages. First, it blinds the process of determining fluoride exposure estimates with respect to the subject's status as a case or a control, be-

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cause this process allows the fluoride level to be collected based on the city or town, irrespective of the subject's status. Next, it is more efficient to collect histories of fluoride concentration for a community once, rather than multiple times, in a study where several subjects have lived in the same city or town. Finally, it ensures consistency of fluoride exposure estimates across individuals residing in the same community.

Single Source Estimate. We used data published in the 1992 CDC Fluoridation Census (1) to determine water fluoride content for each residence at the time the subject lived there. The census is a two-part publication. In one volume, water systems are listed alphabetically by state. For each state, the second volume alphabetically lists communities and identifies the specific system(s) serving each community. The Fluoridation Census reports three categories of public water systems. For adjusted water systems the fluoride level of the water source is adjusted to achieve an optimal target fluoride level. Most of these adjusted water systems add fluoride to increase the fluoride concentration, but a few remove some of the naturally occurring fluoride to achieve an optimal concentration. Natural water systems refer to those systems where fluoride occurs naturally in the water source at a high enough concentration to be in or above the optimal range. A consecutive water system is one which purchases water from either an adjusted water system or a natural water system. The consecutive water systems are listed alphabetically under their respective adjusted or natural water systems, but start dates for purchase contracts are not included.

For each of the 824 distinct communities, we attempted to identify the water system serving the community using the second volume of the Fluoridation Census (1). We used the first volume to obtain fluoride data for each water system and recorded three variables to determine the fluoride level for each residence and time period: (1) the natural fluoride level, (2) the year adjustment of fluoride level was initiated, and (3) the target level of adjusted fluoride. We also reviewed the primary volume of the CDC Fluoridation Census by state to find any communities that otherwise might have been missed. If the city, town, or community was not found in either volume, the fluoride data were considered missing.

Source Documentation Estimate. For the source documentation method, we verified the state and determined the county for each of the 824 communities (city, town, village, hamlet) using the *Columbia Gazetteer* (3). In a few instances, the community name reported did not exist within the state as recorded on the interview form. Using street addresses and/or zip codes from the interview forms, we were able to correct the state designation and verify the existence of the specified address using multiple sources such as maps, atlases, United States Postal Service, Internet search sites, and state or local community agencies. We required at least two sources of information to verify that a community was incorrectly designated within a state. We were able to verify all but one location as existing within a specific state; the fluoride data for this location are considered missing.

We identified contact persons within each state to provide information about the fluoride content of the drinking water for the cities and towns of interest. Our first contact was usually the state dental director's office. If none existed, we contacted another source such as the state department of public health, office of drinking water. For some states, the dental director's office provided all or most of the information needed. However, if they were not able to complete the information, other sources were contacted, often based on their recommendation. These sources included state departments of environmental protection agency, offices of drinking water, water administrators' offices, county health departments (offices of environmental health), local town or city clerks' offices, and specific water systems.

In response to our initial inquiry, three states provided state fluoridation census booklets, which we used as a starting point. We obtained fluoride levels and dates of adjustment of fluoride in public water systems through fax, letter, E-mail, telephone conversation, or personal meeting. If contacts had knowledge or documentation that the source of water had changed for a community during the period of interest and that this change resulted in different fluoride levels for different periods of time, we included this information. If necessary, we requested clarifications or additional information. In the absence of evidence to the contrary, we assumed that the current natural (unadjusted) fluoride level was the level prior to adjustment.

If a community was served by more than one water system, we linked the subject's street addresses to the appropriate water system whenever possible. If the specific address was not available, we calculated an average fluoride level for the water systems unless the fluoride levels differed by more than 1.0 ppm, in which case we considered the fluoride level missing. If information on the proportion of the community served by each water system was available, we calculated a weighted average; otherwise, we used a simple average. We resolved discrepancies in fluoride values or dates reported by different sources by prioritizing information in the following order: local sources (e.g., the specific water company, clerk's office of the city or town); county or state sources (e.g., departments of environmental protection, water administrators' offices or similar state agencies, or state dental directors' offices); or national publications, e.g., 1992 CDC Fluoridation Census (3), 1985 CDC Fluoridation Census (4).

Data Preparation. To compare the single source estimate with the source documentation estimate, we created fluoride exposure history records. First, for each unique address where a subject had ever lived we generated a residential record that included the time period when the subject lived at that address. However, if fluoridation was initiated or discontinued during a subject's residence, we split the residential record into two or three fluoride records to capture the fluoride concentration during each of the time periods.

Statistical Analysis. We calculated summary measures of estimates of fluoride concentration for each method. We used Kendall's tau (5) to measure the correlation between the two fluoride estimates since the distributions of fluoride levels have a substantial number of tied observations. A cross-tabulation was used to demonstrate correspondence between the fluoride levels using the single source method versus fluoride levels using source documentation. We grouped

the fluoride levels into four categories: 0 to 0.3 ppm, >0.3 to <0.7 ppm, 0.7 to 1.2 ppm, and >1.2 ppm. Concordance between fluoride records with non-missing values was calculated as the proportion of fluoride records where the two methods produced estimates in the same category. We determined the number of fluoride records missing fluoride values and the proportion of subjects with missing data for at least one residence for each method.

Results

We attempted to determine fluoride levels for 1,264 residences where subjects in a case-control study stated they used municipal water as their primary source of drinking water. The residences were located in 43 states, Washington DC, and Puerto Rico. The greatest number of residences were from Massachusetts (N=199) followed by California (N=188). A summary of residences per state is provided in Table 1. To reflect the initiation or discontinuation of fluoride adjustment during the time of residence, 55 of the 1,264 residences were split into 2 records, and 3 were split into 3 records each, resulting in a total of 1,325 fluoride records.

Using the single source method, fluoride estimates were determined for 653 (49%) of the fluoride records. For the source documentation method, we were able to estimate fluoride values for 1,318 (over 99%) of the fluoride records. Fluoride estimates were obtained by both methods for 651 fluoride records. When both were available, the fluoride estimates for the two methods were highly correlated (tau=0.85; 95% CI=0.79, 0.90). A cross-tabulation of the two fluoride estimates for the two different approaches is presented in Table 2. When fluoride concentrations for each method were categorized into the four groups shown, we found 96 percent concordance between the methods and most of the discrepancies reflected higher estimates from the single source than by source documentation.

Using the source documentation method, we found fluoride estimates for all but five of the 672 records missing estimates by the single source method. Of 667 fluoride records with missing single source estimates for which source documentation estimates were found, 143 records (21%) had estimates between 0.7 and 1.5 ppm. There were only two records missing a source documentation estimate, but having single source estimates of 2.2 ppm and 2.5 ppm. For these records, the communities were served during the time period of interest by multiple water systems with fluoride concentrations differing by more than 1.0 ppm. Since we could not successfully link these addresses with specific systems, the fluoride values were defined as missing. The proportion of fluoride records with data missing has a substantial impact on the case-control study, since the primary exposure variable is the average lifetime fluoride level. Among the 471 subjects who used municipal water, 326 (62.2%) had missing data for at least one residence using a single source, the 1992 CDC Fluoridation Census, compared to only 7 (1.5%) for source documentation.

Discussion

The empirically developed source documentation approach to estimat-

TABLE 1
Residential Records per State

Records per State	States*	n	No. of Records (%)
150–200	MA, CA	2	387 (31%)
50–149	IL, OH, NY, FL	4	370 (29%)
20–49	NJ, MD, NH, MI, IN, CT, GA, NE, PA, ME, MO, DC	11†	336 (27%)
10–19	RI, VA, IA, PR, CO, TX, VT	6‡	89 (7%)
1–9	LA, KY, NC, WY, ID, NV, TN, AL, OK, SC, SD, WV, AZ, HA, KS, MS, NM, UT, WA, WI	20	82 (6%)
Total		43†‡	1,264 (100%)

*States are listed in descending order of number of records.
†Also includes Washington, DC.
‡Also includes Puerto Rico.

TABLE 2
Comparison of Fluoride Estimates Using 1992 CDC Fluoridation Census Versus Source Documentation

Fluoride Level CDC Census	Fluoride Level Source Documentation					
	0–.3 ppm	>.3–<.7 ppm	.7–1.2 ppm	>1.2 ppm	Missing	Total
0–.3 ppm	0	1	0	0	0	1
>.3–<.7 ppm	0	6	2	0	0	8
.7–1.2 ppm	12	6	593	0	0	611
>1.2 ppm	0	0	5	26	2	33
Missing	414	110	141	2	5	672
Total	426	123	741	28	7	1,325*

*1,325 records represent the total number of fluoride records after they were split as described in the *Methods* section.
Concordance (depicted as the gray shaded area) was 96%, for values with data from both methods.

ing drinking water fluoride content captures a more complete estimate than the method using only a single source, the 1992 CDC Fluoridation Census. The most striking finding was that we were able to estimate fluoride levels for nearly all of the records using source documentation, compared to fewer than half using only the CDC publication. For records where we found fluoride estimates using both methods, the correlation of the estimates was strong and concordance was very high when the fluoride estimates were categorized into four groups.

Our inability to find fluoride estimates with the single source method for half of the residences raises the issue of what estimates to use for the missing values. It might be tempting to assume that the fluoride level is low if it does not appear in the CDC Fluoridation Census. However, using source documentation we found great variability in the range of fluoride levels for these residences; only 62 percent of these estimates were less than or equal to 0.3 ppm and fully 21 percent were at least 0.7 ppm.

Several factors contribute to the number of missing values that resulted from using only the single source method. The 1992 CDC Fluoridation Census reported that approximately 56 percent of the US population had access to optimally fluoridated water and only included information about water systems and communities which met or exceeded this concentration (1). In addition, once a water system adjusted the fluoride level, the original natural fluoride level was not recorded. Since our sample of residential records was drawn from an actual case-control study, these records reflected specific locations for specific time periods and the fluoride level prior to adjustment was often the one needed. However, the fluoride level prior to adjustment was not available when only the 1992 CDC Fluoridation Census was used. Additionally, the water source might have changed, resulting in different fluoride concentrations during the time period prior to adjustment.

The source documentation approach was considerably more labor intensive than using only the CDC publication. It is important for researchers to allocate sufficient time and resources for those efforts when designing their studies. The expanded approach of source documentation used multiple sources to assist in linking residential addresses to communities and water systems that otherwise might be missed if using only the 1992 CDC Fluoridation Census. Some communities, as designated by subjects during an interview, may not always be found under the same name in the CDC Fluoridation Census. For example, the Commonwealth of Massachusetts has identified over 600 communities in Massachusetts that are known by more than one name (6). Some communities are part of other cities or towns and were not listed separately in the CDC publication. Communities might have received water from more than one water system and a local source was needed to link an address with the correct water system. By using multiple sources, we were able to link addresses with specific water systems.

Lastly, accuracy of the fluoride estimate can be compromised when using only the 1992 CDC Fluoridation Census because consecutive systems are linked in the Census with either adjusted systems or natural systems. However, no details about when the consecutive system started purchasing water from another system were provided and we found a number of instances in which purchase began after fluoridation of the primary system.

There are several limitations to our study. First, the process we followed in the source documentation method was ad hoc. Therefore, it might not be easily replicated because *a priori* we did not have a series of precise documentation rules of whom to interview or which local documents to use. This limitation was unfortunately necessary because we could not anticipate all the differences in the organization and responsibilities of state and local agencies and their respective personnel. Our findings may not be generalizable because we used residential records from one case-control study that recruited subjects from tertiary care hospitals located in urban areas. Therefore, we may be overrepresenting urban areas. Although we have 43 states represented in our study, the two having the most residential records (Massachusetts and California) are more influential on results and are not necessarily representative of the whole United States. Finally, the most important general limitation is that neither estimate was independently validated by laboratory tests, so no statement can be made about the accuracy of estimates from either method.

Newer approaches for monitoring, organizing, and maintaining data on fluoride levels as well as other components found in water supplies have recently been implemented. In 1999, annual Consumer Confidence Reports became mandatory for all public water systems and they include information about the fluoride level (7). This information is sent to consumers by their respective water suppliers. The public also may access information through a US Environmental Protection Agency Web site (8). The CDC recently implemented an Internet-based surveillance system in collaboration with the Association of State and Territorial Dental Directors to monitor fluoridation at the local and state level (Water Fluoridation Reporting System) (9). Information is entered and edited directly on the Internet by specific users and enables fluoridation managers to improve the quality of fluoridation. Currently, information about fluoride levels for specific water systems in many states is directly available to the public through a CDC Web site (10).

With these newer systems of data management, researchers conducting prospective studies may be able obtain more complete, current, and accurate information, especially when fluoride concentration is less than the optimal range for dental caries reduction. However, past efforts by state agencies or the CDC to collect and maintain records about fluoride levels and dates of adjustments in water supplies remain valuable and these data should continue to be available to researchers. These records can help provide historic documentation that is needed when conducting case-control studies because an estimate of fluoride level for a particular residence relies on both time and place. Information provided by the newer systems would be helpful in providing a more accurate current snapshot, but will have some of the same shortcomings for case-control studies as the 1992 CDC Fluoridation Census.

In summary, researchers need to be aware of the limitations that exist if they consider using a secondary data source for estimating fluoride in drinking water, particularly when

fluoride is the primary exposure of interest for an investigation. When fluoride estimates were needed for the study population in our case-control study, the importance of the proportion of missing data emerged and through source documentation we were able to determine reasonable estimates for these data. Although this method is labor intensive, it has been incorporated into a large ongoing case-control study of bone disease being conducted by the National Cancer Institute.

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