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Relationship of Naturally Occurring Fluoride in Carroll County, Maryland to Aquifers, Well Depths, and Fluoride Supplementation Prescribing Behaviors

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Purpose. Systemic fluorides are effective in the prevention of dental caries but over ingestion can lead to dental fluorosis. Fluoride supplements may be under-prescribed for children residing in areas where drinking water is derived from wells, because of a lack of knowledge of dental providers or the effort required to test wells for fluoride before prescribing supplements. The purpose of this study was to determine the possible factors associated with fluoride content of well water in a specific county in Maryland, and to determine whether there is a relationship between the amount of naturally occurring fluoride in the well water and the child's fluoride supplementation use.

Methods. This study analyzed the fluoride prescribing behavior and the fluoride content of wells from a sample of 197 Carroll County, Md residents. Those individuals that answered a questionnaire about well depth and use of fluoride supplements subsequently were mailed a water testing kit. Water samples were tested for fluoride using a fluoride specific ion electrode. Derivations of well water supplies (aquifers) were obtained from a county geologist. Variance in well depth and aquifer type were correlated to the levels of naturally occurring fluoride. Supplementation practices of children residing in the participating sampled households were compared to results of fluoride analyses of individual wells.

Results. Results showed that Carroll County well water contains negligible to low levels of fluoride (0.08-0.24 ppm). Pearson r testing showed a positive relationship between well depth and fluoride, $r = 0.23$ ($p \leq .01$). ANOVA results showed no significant difference between the 3 aquifers fluoride, $p = 0.23$. Analysis of the supplementation behavior indicated that the majority (58%) of the children that should have received fluoride supplements were receiving the incorrect dosage or not being supplemented.

Conclusion. Fluoride content of well water may be related to well depths. Fluoride supplementation practices generally were incorrect, even for this community whose wells had less than optimal fluoride content. Fluoride supplementation education may be lacking for dentists, physicians, and their patients. Future research should explore whether there is a relationship between well depth and fluoride content, as found in this study, and the variables associated with the incorrect fluoride prescribing behaviors.

Keywords: well water, fluoride, fluoride supplements, aquifers

Introduction

Topical and systemic fluorides are known to be highly effective therapeutic components of a comprehensive caries prevention plan.[1] With regard to systemic fluoride, approximately 15% of the US population receives drinking water that is regarded as fluoride deficient, ie, less than 0.6 ppm.[2] Fluoride supplements were developed as a way to provide caries-preventive benefits to children living in such non-fluoridated areas.[3]

To optimize fluoride in the drinking water, municipalities often add fluoride to community water supplies, but fluoride also may be naturally occurring in groundwater.[4] Underground aquifers acquire fluoride compounds when minerals in rocks are dissolved through water percolation, as well as from contamination.[5] Today's wells are being drilled deeper in order to supply enough water for household consumption, and such deeper wells require water to travel through more rock sediment before reaching the exit point. Well depth or differences in aquifers may affect the presence and amount of naturally occurring fluoride. Because of the variability of fluoride in wells it is recommended that drinking water supplies are tested before fluoride supplements are prescribed to children.[6] However, it is believed that prescriptions are often dispensed without accounting for the possibility of naturally occurring fluoride in the child's well water.[1]

The purpose of the present study was to determine the levels of naturally occurring fluoride in one county in Maryland and to relate these finding to the reported depths of the wells and to the aquifer from which the water was derived. Additionally, through a survey of the household from which the water was obtained, an analysis of the number of children who were receiving optimal fluoride, either through naturally occurring fluoride or through fluoride supplements, was calculated.

Review of the Literature

The effects of naturally occurring fluoride on dental enamel was first documented in 1901 when Frederick S. McKay, DDS, and G.V. Black, MD, observed a discoloration of enamel in their patient population; known by local inhabitants as "Colorado Brown Stain." The term "mottled enamel" was applied to this enamel defect in 1916.[7] McKay and Black realized that mottled enamel was occurring only in certain geographic locations: individuals all consuming drinking water with fluoride levels ranging from 2-12ppm.[8]

In 1931, H. Trendley Dean, DDS, investigated the association between naturally occurring fluoride in drinking water and the prevalence and severity of mottled enamel.[9] Dean found that at levels between 1.7-2.5 ppm, children were predominately caries-free. Dean hypothesized that an inverse relationship existed between fluoride consumption and caries prevalence. Studies by Dean in the 1940s concluded that fluoride concentrations ranging between 0.7- 1.2 ppm was optimal for caries control and prevention without producing dental fluorosis.10 Water fluoridation, beginning in 1945, reflected these conclusions.

In order to address the many children that could not consume optimally fluoridated water, fluoride dietary supplements were introduced in 1958. The Council of Dental Therapeutics of the American Dental Association published recommendations for fluoride supplementation after clinical trials in the 1940s had proven their safety.[11,12] A literature review of 21 clinical trials on fluoride supplementation by Driscoll in 1974 found 50-80% caries reduction in the primary and permanent dentition when supplementation was started before 2 years of age.[13]

Fluoride is now contained in many foods and beverage products because they are processed with fluoridated water systems. The risk of developing enamel fluorosis is positively related to the ingestion of fluoride at above optimal levels, considering all sources such as: drinking water, prescribed supplements, dentifrices, mouthrinses, and food & beverages prepared with fluoridated water sources.[14]

In 1994, the Centers for Disease Control (CDC) issued a revised schedule for the recommended dosage of fluoride supplementation that reflects a dosage based on the fluoride level of an individual's water source (Table 1).[15] To correctly

utilize the CDC's guidelines, drinking water must be tested for fluoride content in order to avoid inappropriately prescribing fluoride supplements.

Table 1. Fluoride supplementation levels based on fluoride ppm (parts per million) in drinking water (CDC 1994)

Age	< 0.3 ppm	0.3 - 0.6 ppm	> 0.6 ppm
Birth – 6 months	None	None	None
6 months - 3 years	0.25 mg/day	None	None
3 - 6 years	0.50 mg/day	0.25 mg/day	None
6 - 16 years	1.0 mg/day	0.50 mg/day	None

Currently, only 2 studies addressing naturally occurring fluoride levels in US well water have been identified-one in Texas and the other in the southwest region of Maryland.[16,17] Numerous counties in Texas were found to have fluoride levels ranging from < 0.1- > 5.0 ppm.16 Southern and eastern counties in Maryland reportedly have well water fluoride levels ranging from ≤0.01- 5.0 ppm.[17] To date, no study has analyzed Carroll County, Md well water for the possibility of naturally occurring fluoride.

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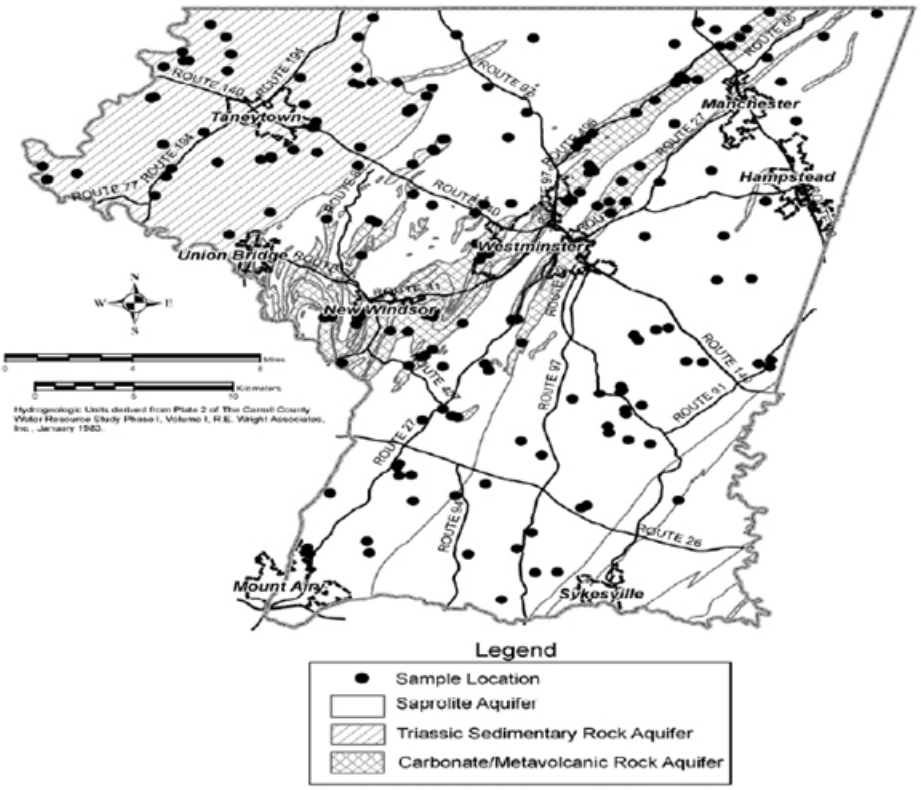
Even though this review proved water fluoridation and the prescribing of fluoride supplements are effective at preventing caries, there is always the possibility of dental fluorosis due to inappropriately prescribed supplementation because well water was not tested for fluoride content before fluoride supplements were prescribed.

Methods

Before this study began, the Institutional Review Board of the University of Maryland School of Medicine approved the protocol. The population for this study was individual home-based wells in Carroll County, Md, selected from approximately 33 000 households.[19] In order to have relatively equal sampling from the 3 aquifers, a Carroll County Environmental Health Department ground water specialist stratified the well permits into the 3 separate aquifer databases. Every "nth" well permit was randomly selected from each aquifer database until the desired sample size of approximately 200 from each aquifer was reached. The final sample consisted of 632 registered well permits (Figure 1).

Figure 1. Geographic distribution of the final sample



Selected study participants were mailed a self-administered survey (Figure 2). A cover letter provided background information and a statement of informed consent. The survey included questions regarding the age of the home, water filtration use and type, history of home fluoride testing, number and age of children living in the household, and whether any children were receiving fluoride supplementation, and if so, what was the dosage.

Figure 2: Survey

UNIVERSITY OF MARYLAND, DENTAL SCHOOL

Department of Health Promotion and Policy
Programs of Pediatric Dentistry, Dental Hygiene and Health Services Research

Information Questionnaire
Please answer all questions as they pertain to your home

1. Is your home currently on a well water system? Yes___ No___
   If no, discontinue answering the questionnaire and return this form in the envelope provided.

2. Approximately how old is your home? _____

3. How long have you been living at this home? _____

4. Do you have water filters on your kitchen sink? Yes ___ No ___
   Do you have water filters on your entire home system? Yes ___ No ___
   If yes, please indicate what brand _____.

5. Has your home's well water system ever been tested for fluoride content before?
   Yes ___ No ___

6. Are there children presently residing in the home, if so what are their ages?
   Yes ___ No ___ Ages _____

7. Has fluoride been prescribed for children living in the home?
   Yes ___ No ___
   If yes, check the corresponding dosage below and indicate the child's age.
   Tablet or Liquid 0.25 mg _____ 0.50 mg _____ 1.00 mg _____

8. Name and Address: _____
   _____
   _____

*Please mail questionnaire in the enclosed envelope as soon as possible. Your water testing kit will arrive shortly after receipt of this questionnaire. Thank you for participating in this study!

666 W. Baltimore St., Room 3-E-10 * Baltimore, Maryland 21201-1586 * 410 706 7970 * 410 706 3028 fax

Upon the return of a completed survey, participants were mailed a water-sampling kit. Home addresses were linked to the registered well permit number to retrieve information regarding well depths for each participating household to determine if there was a correlation between the amount of naturally occurring fluoride and the depth of the well.

The water was analyzed for fluoride content using a fluoride ion selective electrode and compared to fluoride standards of 0.1, 0.2, 0.5, and 1.0 ppm F. This is the preferred method for fluoride measurement due to its accuracy of approximately + 2 %, accounting for measurement and temperature error.[20] Samples measuring below 0.1 were considered negligible, and for statistical purposes, were considered as 0.08 ppm. Fluoride samples were plotted against geologic maps that designated the distribution of the aquifers in Carroll County. Pearson's r was conducted to test if well depth was related to the level of naturally occurring fluoride. Additionally, the results of the fluoride content were compared to the survey results reporting fluoride supplementation practices.

Results

Thirty-three percent, or 197 of 632, selected study participants returned a completed survey and provided a well water sample for fluoride analysis. Of the 197 samples tested for fluoride, none proved to contain biologically important amounts (≤.3 ppm) of naturally occurring fluoride. Approximately 7% of the well water samples produced fluoride levels ranging from 0.1-0.24 ppm (Table 2).

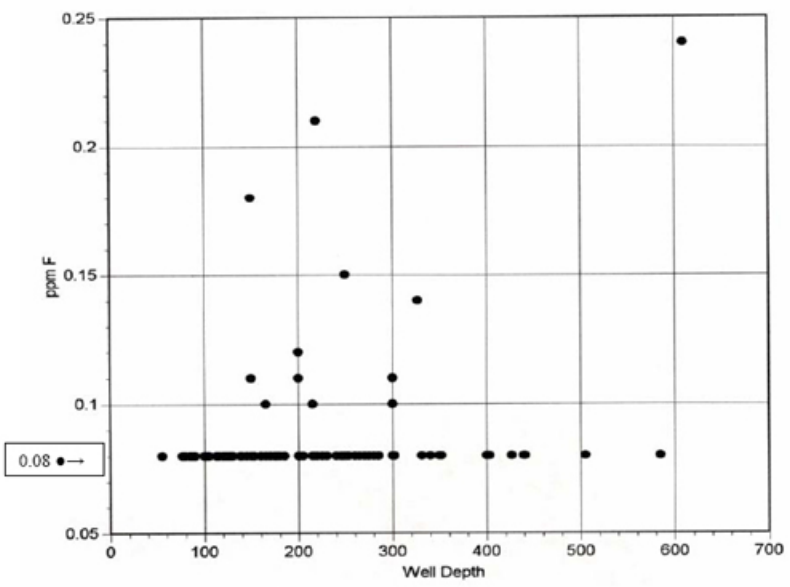
Table 2: Measurable well water sample fluoride levels of the three aquifers.

Aquifer	Samples producing measurable results: Yes	No
Total Carroll County	**14 (7%)**	**183 (93%)**
Carbonate	1 (1%)	69 (99%)
Saprolite	3 (4%)	70 (96%)
Triassic	10 (19%)	44 (81%)
	$\chi 2 = 15.444$	$p \leq .001$

Figure 1 shows the stratified distribution of well water samples tested within the 3 aquifers. Sample distribution was spread evenly throughout each of the 3 aquifers. Analysis of Variance (ANOVA) was used to test if there were differences in fluoride concentration in the Carbonate, Saprolite, and Triassic aquifers of Carroll County. There was no significant difference in the naturally occurring fluoride levels between the 3 aquifers ($F = 1.466$, $p = 0.23$).

Wells in the study sample ranged in depth from 70 to 700 feet. There was a significant, positive relationship between the amount of naturally occurring fluoride and the depth of the wells in Carroll County, Md ($r = 0.23$, $p \leq 0.01$). As well depth increased, so did the amount of naturally occurring fluoride (Figure 3).

Figure 3: Scatter diagram of samples based on well depth and ppm fluoride



Sixty-eight of the surveyed homes noted having at least one child within recommended fluoride supplement age range (6 months-16 years), for a total of 129 children. Of the 129 children included in this study, 54 (42%) received a correct supplement dosage while 75 (58%) received an incorrect dosage based on the age of the child and supplement dosage

reported on the survey (Tables 3 and 4). Of the 75 children who reportedly received an incorrect dosage, 8 received a dosage that was too high, 20 received a dosage that was too low, and 47 were not receiving a supplement that should have been, based on the CDC's revised schedule for fluoride supplementation (Table 1).

Table 3: Carroll County supplementation practices and dosage accuracy, for individual household children.

Children receiving fluoride supplements	Dosage Accuracy	
	Correct	Incorrect
Total Carroll County	**54 (42%)**	**75 (58%)**
Yes	54 (66%)	28 (34%)
No	0 (0%)	47(100%)

$\chi 2 = 50.565$ $p \leq .001$

Table 4: Aquifers dosage accuracy, too high or too low, for homes reporting inaccurate dosages on the survey.

Aquifer	Children receiving fluoride supplements	
	Too High	Too low
Total Carroll County	**11 (39%)**	**17 (61%)**
Carbonate	1 (11%)	8 (89%)
Saprolite	5 (45%)	6 (55%)
Triassic	5 (62%)	3 (38%)

$\chi 2 = 4.978$ $p > .05$

Discussion

In the United States, approximately 60% of the population is exposed to fluoridated public water, at a cost of approximately $0.75 per person each year.[1] Fluoridation of the public water systems from the 1940s-1960s showed a caries reduction from 50% to70%, but studies in the 1980's found that caries reduction averaged at 26%.[21] Fluoride ingested through drinking water is absorbed in small doses throughout a day. Frequent exposure to small amounts of fluoride on a daily basis is ideal to reduce a child's risk for dental caries, with the optimal fluoride concentration between 0.7- 1.2 ppm.[22] The CDC now recommends that fluoride supplements be discretionarily prescribed to children that are considered high risk for dental caries, whose primary drinking water source has low fluoride levels.[1]

To date, few studies have addressed the testing of well water for naturally occurring fluoride in the United States and no study has addressed the relationship between well depth and naturally occurring fluoride. In our present study, the relationship

between well depth and fluoride content was significant. However, it should be noted that well depth accounts for only a small percentage of the factors that influence fluoride levels in the well water. Further study of well depth and fluoride levels is required to see if such correlations are consistent in other geographic locations.

The quality of the groundwater is determined by variables affecting the underlying aquifer, such as soil characteristics, agricultural activities, and manufacturing corporations found in the region. Naturally occurring fluoride can originate from the aquifers rocks and minerals, agricultural fertilizer runoff, and many manufacturing chemicals. Since there are 3 distinct aquifer rock systems that serve Carroll County, it was hypothesized that there would be a significant difference in the amount of naturally occurring fluoride between the 3 separate aquifers. Results, however, showed that differences in aquifer type in this particular county did not have a significant affect on the amount of naturally occurring fluoride in the well water.

It also was hypothesized that if biologically significant amounts of fluoride were present in Carroll County well water, and children residing in these homes were prescribed a fluoride supplement, the resulting dosage could put them above the CDC recommended daily requirements for children considered at high risk for dental caries. The results of this study show the opposite was true; low levels of fluoride found in the well water (0.08-0.24 ppm) actually resulted in the under-prescribing of fluoride supplements for the children of this county.

Because the survey in this study found that fluoride supplements in an essentially non-fluoridated area were underutilized, a broader study may be required to determine the utilization of fluoride supplements in other communities, and whether caries risk of the children has any effect on the practices of fluoride supplementation. To better understand the lack of compliance with fluoride supplement regimens, further research should include the following questions. For those children who are taking a fluoride supplement, where is the prescription coming from? If fluoride supplements are under-prescribed, what is the reason? Was the child prescribed fluoride supplements, but is no longer taking them? How often does the child take fluoride supplements, daily or sporadically? Does the child taking, or not taking, supplements have any untreated carious lesions or restorations, and if so how many? Answers to these questions would expand the knowledge regarding fluoride supplementation and guide education reform.

The 2 major findings of this study were that fluoride content of well water may be related to well depths in a nonfluoridated community and fluoride supplementation practices were generally incorrect. Shortcomings of the present study were that there was no collection of caries risk data of the children as well as no exploration of alternative sources of fluoridated drinking water, such as school water or bottled drinks. Future studies should further explore the relationship between wells variables and fluoride levels, examine the possible effect of caries risk categorization on fluoride supplementation prescribing behaviors, and investigate other potential variables that may affect fluoride prescribing behaviors.

Dental hygienists work in collaboration with dentist employers and patients' physicians to consider fluoride prescriptions for their pediatric population. New patients are often screened for medical and dental health history by the dental hygienist. It is imperative for health care specialists to be educated with information regarding the fluoride content of each patient's drinking water before determining optimal dosage requirements. Physicians and dentists who prescribe fluoride supplements need to be aware of the level of naturally occurring fluoride in their patients' local water supplies, and educate their patient population regarding the use of fluoride supplementation as recommended by the Center for Disease Control, American Dental Association, American Academy of Pediatrics, and American Academy of Pediatric Dentistry.[1,6,23,24] Additionally, parents need to be educated on the importance of the first dental visit by the child's first birthday so they can be informed about fluoride supplementation. Thus, all health care providers that see children need to understand the value of fluoride supplementation based on the fluoride content of their patients' drinking water, as well as each child's caries risk.

Conclusion

The present study produced data on naturally occurring fluoride in well water, well depth and fluoride levels, and fluoride supplementation practices in one community in Maryland. Results of this study show that this community's water supply contained low levels of naturally occurring fluoride (0.08-0.24 ppm). However, there was a significant positive relationship between well depth and fluoride levels. Approximately one-half of the children in this community were receiving fluoride supplementation to optimize daily fluoride exposure.

Future studies need to examine naturally occurring fluoride in groundwater in other geographic regions in the United States to determine if daily water consumption has an affect on the collective fluoride ingestion for the residents. Additionally, studies should address compliance with systemic fluoride regimens in light of community fluoride levels and caries risk of the youth population.

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Notes

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