ORIGINAL CONTRIBUTION

Fluoride and Bacterial Content of Bottled Water vs Tap Water

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Context: Bottled water has become a status symbol and is frequently used in place of tap water. While both waters are considered safe to drink, is either more beneficial in preventing tooth decay and is there a difference in purity?

Objective: To determine the fluoride level and bacterial content of commercially bottled waters municipal tap water and to compare the results.

Design: Comparative study.

Setting: Cleveland, Ohio.

Sample: Fifty-seven samples of 5 categories of bottled waters were purchased from local stores. Samples of tap water were collected in sterile containers from the 4 local water processing plants. Fluoride levels were determined by an ion-selective electrode method. Water was cultured quantitatively and levels of bacteria were calculated as colony-forming units (CFUs) per milliliter.

Main Outcome Measure: Fluoride levels and bacterial counts.

Results: Fluoride levels within the range recommended for drinking water by the Ohio Environmental Protection Agency, Cincinnati, 0.80 to 1.30 mg/L, were found in only 3 samples of bottled water tested. The fluoride levels of tap water samples were within 0.04 mg/L of the optimal fluoride level of 1.00 mg/L. The bacterial counts in the bottled water samples ranged from less than 0.01 CFU/mL to 4900 CFUs/mL, including 6 samples with levels substantially above 1000 CFUs/mL. In contrast, bacterial counts in samples of tap water ranged from 0.2 to 2.7 CFUs/mL.

Conclusions: Five percent of the bottled water purchased in Cleveland fell within the required fluoride range recommended by the state, compared with 100% of the tap water samples, all of which were also within 0.04 mg/L of the optimal fluoride level of 1.00 mg/L. Use of bottled water based on the assumption of purity can be misguided. Recently, the Environmental Protection Agency, Washington, DC, published a final ruling that requires community water systems to regularly report to the public on the quality of local tap water; there are no similar proposals to determine the quality of bottled water through labeling.

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THE SOURCE of tap water for Cleveland is Lake Erie. Water is pumped by 4 water plants and serves more than 1.5 million customers (Nicholas G. Pizzi, written communication, September 1998). The process of water purification at the Cleveland water plants, which is similar to the process used in most US water plants, consists of many intricate steps and includes the use of chemicals and filters. After the lake water is screened of fish and debris, chemicals such as chlorine, which acts as a disinfectant, and aluminum sulfate and potassium permanganate, which remove impurities, are added. The process of mixing the chemicals with raw water is called flocculation, which results in the eventual sedimentation of impurities. After removal of the sediment, the partially purified water is run through a series of filters consisting of coal, sand, and several layers of gravel activated by minute electrical charges that force impurities into the filter medium. Fluoride is added at a regulated concentration. The 4 water plants have been fluoridating drinking water for more than 30 years and are required by the Ohio Environmental Protection Agency, Cincinnati, to maintain fluoride levels within the range of 0.8 to 1.3 mg/L.[1] Ohio is one of 10 states that mandate fluoridation of public water supplies. Communities with 5000 or more residents using public water supplies must receive optimally fluoridated water.

The use of bottled water may have begun as a fad, but the industry has evolved into one of the fastest growing industries

MATERIALS AND METHODS

Fifty-seven samples of 5 categories of bottled water were purchased from as many pharmacy, grocery, discount, and wholesale stores in Cleveland as possible to capture the total market share. Samples of tap water were collected in sterile containers from the 4 local water treatment plants. After receiving permission to obtain water samples from the 4 Cleveland water plants, we collected 4 water samples from each plant on unannounced visits. To simulate the collection of bottled water samples, tap water was collected at its point of origin. It was believed that the quality of tap water collected outside of the water plant, eg, at a residence or business, could be altered by residential or commercial plumbing or filtration systems. All water samples were transported to the Ohio Department of Health Laboratories, Columbus, for analysis. At the state laboratory, technicians measured 200-mL samples of water into sterile containers, each numbered with a key retained only by the investigators. Because the laboratory technicians were blinded to the type of water contained in the samples, any potential bias was eliminated. Furthermore, as a quality control measure, 10% of all samples were double-tested to verify results. The fluoride levels were measured by the standard method for measuring fluoride level in water as recommended by the Environmental Protection Agency (Washington, DC), using an ion-selective electrode (Expandable Ion Analyzer EA920; Orion Research Incorporated, Cambridge, Mass).[19] The bacterial count was derived from 100 mL of each water sample passed through a filter (0.45-µm Millipore HA Filter; Millipore Corporation, Bedford, Mass) and cultured on agar (Bacto Plate Count Agar; Difco Laboratories, Detroit, Mich). Colonies were counted and colony-forming units (CFUs) per milliliter were calculated. Samples with confluent colonies were refiltered at 10 mL and 0.1 mL per sample and CFUs per milliliter were calculated. Owing to budget constraints, duplicate samples of tap water or bottled water were not collected or analyzed.

in the United States, with yearly sales of almost 4 billion gallons.[2] Bottled water is popular among adults and children of all ages. In a survey of more than 1000 pediatric patients, Flaitz et al[3] found that more than 9% of children used bottled water as their primary source of drinking water. Bottled water has become a status symbol and is frequently used in place of tap water because of convenience, pleasing taste, and perceived purity.

Bottled water comes from a variety of sources and can be purified in several ways. Spring water is water derived from an underground formation from which water flows naturally to the surface of the earth. Artesian water, or artesian well water, is dervived from a well that taps a confined aquifer. Water that has been produced by distillation, deionization, reverse osmosis, or another process and that meets the definition of purified water or purified drinking water may be called purified water or demineralized water. Water may be called distilled water if it has been produced by distillation.[4] Most bottled water contains less than 0.30 mg/L of fluoride, and while the US Food and Drug Administration, Rockville, Md, has regulations that limit the fluoride content, it does not require fluoride levels to be optimal for the prevention of tooth decay or to be listed on the label. Bottled water packaged in the United States to which no fluoride has been added should not contain fluoride in excess of 2.4 mg/L based on the annual average maximum daily air temperature at the location where the bottled water is sold at retail (range of fluoride level, 2.40 mg/L in areas with temperatures <12.1°C to 1.40 mg/L in locations with temperatures >26.2°C).[4] Imported bottled water to which no fluoride is added should not contain fluoride in excess of 1.40 mg/L. On the other hand, bottled water packaged in the United States to which fluoride has been added should not contain fluoride levels in excess of 1.70 mg/L in areas with temperatures lower than 12.1°C, and in excess of 0.80 mg/L in areas with temperatures higher than 26.2°C. Imported bottled water to which fluoride is added should not contain fluoride levels in excess of 0.80 mg/L.[4]

In the Safe Water Drinking Act, the federal government specifies safe levels of fluoride and bacteria, among other substances, for drinking water.[5] Major microbiological problems with either tap water or bottled water in healthy populations are rare. However, either water supply can be unsafe, as shown in the 1993 parasite outbreak of cryptosporidiosis in Milwaukee, Wis, that sickened 403 000 residents.[6] Sewage and excrement are the most common sources of bacterial contamination and danger to public health associated with all types of drinking water. While contamination is rare, no water is pure and bacteria will proliferate in minimally contaminated water that is not refrigerated. However, water plant operators claim that tap water is safe and bottled water manufactures promote their product as pure or impeccably clean.

Enamel fluorosis is a demineralization of the dental enamel (outermost layer of tooth structure) caused by excessive ingestion of fluoride during the years of tooth calcification.[7] Its appearance can range from very mild (barely noticeable whitish striations only on portions of the teeth) to very severe (heavily stained with pitting on all surfaces of the teeth). Enamel fluorosis is perceived as an aesthetic problem.[8] Fluoride levels in optimally fluoridated tap water differ substantially from fluoride levels in bottled water.[1,4] The use of optimally fluoridated water is a major factor in the prevention of tooth decay, especially in children.[9] Although the consumption of sugar continues to rise in the United States,[10] dental decay among children continues to decline, with most researchers pointing to the use of fluoride in its various forms as the main reason.[11] Therefore, for children drinking nonfluoridated water (<0.70 mg/L), the American Dental Association (Chicago, Ill),[12] the American Academy of Pediatrics (Elk Grove Village, Ill),[13] and the American Academy of Pediatric Dentistry (Chicago)[14] recommend fluoride supplements. Additionally, fluoridation has been found to reduce caries in adults. Researchers have shown that root caries in areas with fluoridated water are less prevalent than in areas without fluoridated water.[15,16] In Cleveland, water plant op-

Table 1. Bottled Water Tested for Fluoride Levels and Bacterial Counts*

Water Type	No. of Specimens	Fluoride, mg/L	Bacteria, CFUs/mL
Spring	16	<0.10	<0.01-0.01
	4	<0.10	0.02-0.34
	4	<0.10	~6.00-29.00
	1	<0.10	~1500.00
	2	0.13	<0.01-0.01
	1	0.13	~1700.00
	3	0.14-0.19	<0.01-0.01
	1	0.23	~530.00
	1	0.23	~2000.00
	1	0.27	0.10
	2	0.47-0.73	<0.01
Artesian	3	<0.10-0.17	<0.01-0.01
	1	0.25	~2400.00
Purified	1	<0.10	0.02
	2	<0.10	~28.00-30.00
Distilled	3	<0.10	<0.01-0.01
	2	<0.10	0.23-1.10
	1	<0.10	~19.00
Drinking	1	<0.10	<0.01
	2	<0.10	0.14-0.15
	1	<0.10	~21.00
	1	0.65	~4900.00
	2	0.90-0.94	<0.01-0.01
	1	0.92	~1500.00

*CFUs indicates colony-forming units.

erators target the recommended fluoride level of 1.00 mg/L. However, the fluoride in bottled water packaged in the United States and sold in Cleveland ranges from negligible amounts to levels higher than 2.00 mg/L. In a study of 78 bottled water brands in Iowa,[17] 83% contained less than 0.30 mg/L of fluoride, 7% contained 0.30 to 0.70 mg/L, 1% contained 0.71 to 1.00 mg/L, and 9% contained more than 1.00 mg/L. MacFadyen et al[18] found some bottled spring waters that contained extremely high levels of fluoride that could potentially cause enamel fluorosis if consumed by children younger than 8 years. The purpose of this study is 2-fold: (1) to determine the fluoride levels and bacterial counts in bottled waters purchased in Cleveland and (2) to compare these values with those of tap water processed by the 4 water plants in Cleveland.

RESULTS

Only 3 bottled waters, all 3 classified as drinking water, had fluoride levels within the range recommended by the Ohio Environmental Protection Agency. The fluoride levels of these 3 samples were 0.90, 0.92, and 0.94 mg/L, just short of the optimal fluoride level of 1.00 mg/L. Most of the bottled water samples tested had less than 0.74 mg/L of fluoride, which is short of the accepted range of 0.80 to 1.30 mg/L of fluoride-adjusted drinking water, as recommended by the Ohio Environmental Protection Agency. Of the 57 brands of bottled water, 51 (89%) contained less than 0.30 mg/L of fluoride, 1 (2%) contained 0.30 to 0.60 mg/L, and 5 (9%) contained 0.61 to 1.00 mg/L (**Table 1**). By law, the manufacturers of bottled water are only required to test for fluoride once a year. The fluoride levels of all tap water samples were within 0.04 mg/L of the optimal fluoride level of 1.00 mg/L. To compare our measurements of fluoride levels with the levels measured by the bottled water manufacturers, we attempted to contact as many manufacturers as possible. Of the 57 manufacturers, we were able to contact 37 by telephone from information printed on the labels. Thirty-seven manufacturer representatives were interviewed by telephone and were asked to provide the fluoride level of their product. Thirty-three of the 37 claimed that the fluoride level of their product was within 0.10 mg/L of our results, 3 responded with lower fluoride levels (an average of 0.24 mg/L lower), and 1 indicated a fluoride level that was double that of our tested sample.

The bacterial colony counts ranged from less than 0.01 to 4900 CFUs/mL among the 57 samples of bottled water tested. Thirty-two samples contained less than 0.02 CFU/mL, 10 samples contained between 0.02 and 1.10 CFU/mL, 8 samples contained between 6 and 30 CFUs/mL, 1 sample contained 530 CFUs/mL, and 6 samples contained between 1500 and 4900 CFUs/mL (Table 1). In contrast, the 4 samples of tap water varied slightly from 0.2, 1.2, 1.7, and 2.7 CFUs/mL, which was not surprising because the 4 water processing plants treat water similarly. Tap water was purer than 15 samples of bottled water, while 3 samples of bottled water were basically as pure as the tap water, but tap water was not as pure as 39 samples of bottled water. The 15 samples of bottled water that were not as pure as tap water contained significantly more bacteria. Of those 15 samples, the bacterial counts were more than twice that of the most contaminated tap water sample drawn from the water plants to almost 2000 times that of the highest tested tap water sample. When comparing the average bacterial counts of the 4 water plants (1.5 CFUs/mL) with each of the 57 samples of bottled water, 14 samples of bottled water contained at least 10 times the bacteria of tap water. Of the 14 samples, 6 contained at least 1000 times the bacteria of tap water.

COMMENT

Bottled water should be required to meet the same standards for fluoride levels and bacterial content as tap water, as it makes up a significant proportion of the water consumed by the public. The current efforts to produce annual consumer confidence reports on the quality of local tap water is a reflection of the general interest in providing information to the public in the United States.[20] These reports will require water suppliers to inform customers on a variety of water-quality issues, such as the source of the water, the susceptibility of the source to contamination, the levels of any contamination, standards for comparison, the sources of contamination and potential health effects, and the overall compliance with other water-related rules. For the first time, water suppliers have started issuing consumer confidence reports; the deadline for all such reports for 1999 was October 19th. Thereafter, consumer confidence reports must be made available to consumers by the first of July each year. The benefits of this public health initiative are lost if the public consumes large amounts of water from other,

unregulated sources. This study demonstrates that bottled water is not a consistent product and that different brands contain fluoride levels and bacterial counts that vary greatly.

The fluoride levels in bottled water sold throughout the country can vary substantially, from less than 0.01 to 4.00 mg/L. By law, tap water cannot contain more than 4 mg/L of fluoride,[21] and bottled water must not contain more than 2.4 mg/L.[4] More than 52% of the US population is provided with optimally fluoridated tap water adjusted between 0.7 and 1.20 mg/L according to the maximum mean air temperature. The recommendation of the US Public Health Service (Rockville, Md) for fluoridating public water supplies in the southern portions of the United States is 0.70 mg/L, while the recommendation for the northern portions is 1.20 mg/L. Another 4% of the US population is served with water naturally fluoridated at or above 0.70 mg/L, with only a few areas with levels exceeding 2.00 mg/L and none exceeding 4.00 mg/L. The remaining 44% of the US population receives water deficient in fluoride, ie, water containing levels less than 0.70 mg/L.[21] Healthy People 2000[22] called for 75% of the water serving US residents to be optimally fluoridated. The draft of Healthy People 2010[23] proposes a new target of at least 85% of the population to be served by optimally fluoridated water. These target objectives for fluoride are important for the continual decline in tooth decay in children and adults. However, if more children and adults use bottled water as their primary source of drinking water, the incidence of tooth decay may increase, because most bottled water contains low levels of fluoride.

In Cleveland, the public water supply is fluoridated, and the Ohio Environmental Protection Agency requires fluoride levels to be maintained between 0.80 mg/L and 1.30 mg/L, with an optimal level of 1.00 mg/L according to the maximum mean air temperature of the region. Only small variations in fluoride levels exist among the 4 water plants, ie, 0.99 mg/L, 1.02 mg/L, 1.03 mg/L, and 1.04 mg/L, all of which are very close to the optimal 1.00 mg/L. Customers drinking tap water in Cleveland are drinking optimally fluoridated water, which can be verified by daily logs of fluoride levels. However, the use of certain home water filtration products can remove some or almost all fluoride from the water; eg, filtration by distillation or reverse osmosis removes most of the fluoride, while carbon or charcoal filtration units do not remove much fluoride. In bottled water available for purchase in the Cleveland area, the fluoride levels varied from less than 0.10 to 0.94 mg/L, with the fluoride levels of only 3 brands falling within the recommended range. Bottled water tested in this study had fluoride levels similar to bottled water in the Iowa study,[17] in which 78 brands of bottled water were tested. Most products studied contained less than 0.3 mg/L of fluoride, with 83% in the Iowa study[17] and 89% in this study. Because dietary fluoride supplements are recommended for children whose primary drinking water source is low in fluoride (**Table 2**), children should be considered for prescribed fluoride supplements if they drink bottled water.[12-14] However, 9% of the bottled water sold in Cleveland contains fluoride levels greater than 0.60 mg/L and therefore requires no additional fluoride from dietary supplements. Several researchers have reported that children drinking water with adequate fluoride levels were prescribed supplements inappropriately.[24-26] The only way to determine the fluoride level in bottled water is to have the water tested or to contact the manufacturer, as the information is not available on the labels. The cost of water testing ranges from $10 to $20 per sample. We attempted to contact the manufacturers of the 57 bottled waters collected, but were only successful in reaching 37. Although most listed telephone numbers or locations on the label, we were unsuccessful in reaching a company representative by telephone 35% of the time. If we succeeded in reaching a manufacturer, it often took several attempts to gather the desired information. The information received from the manufacturers was usually within 0.1 mg/L of the fluoride level of the water as measured by our laboratory. Manufacturers should be required to list the fluoride level on their labels. Presently, manufacturers are only required to declare the addition of fluoride to their product, not the level of fluoride.

Table 2. Fluoride Supplementation

	Water Fluoride Content, mg/L		
Age	<0.30	0.3-0.6	>0.6
Birth to 6 mo	0.00	0.00	0.00
6 mo to 3 y	0.25	0.00	0.00
3 to 6 y	0.50	0.25	0.00
6 to 16 y	1.00	0.50	0.00

The microbiological quality of bottled water was analyzed according to the *Standard Methods for the Examination of Water and Wastewater*.[19] In the chapter on microbiological examination, the coliform group of bacteria is described as the principal indicator of bacteriological quality of water supplies. The presence of any coliform bacteria is taken to represent fecal contamination and renders the water unsatisfactory and potentially unsafe. Processed drinking water should not contain coliforms. In fact, coliforms are the only microbiological contaminant to be regulated by law in both tap and bottled waters. For tap water, Ohio administrative code 3745-81-14 (which specifies the maximum contaminant levels for microbiological contaminants) states that a public water system that tests at least 40 samples per month (all 4 Cleveland water plants fall in this category) must be in compliance with the maximum contamination level for total coliforms when no more than 5% of the total number of samples during a month are positive for coliform. Any repeated sample positive for coliform bacteria is a violation of the maximum contaminant level for total coliforms, and may pose an acute risk to human health. Public notification must be provided in accordance with rule 3745-81-32 of the administrative code.[27] Bottled water is also tested annually by the membrane filter method by the Division of Food Safety, Ohio Department of Agriculture, Reynoldsburg, as mandated by the US Food and Drug Administration. Under this regulation, not more than 1 of the analytical units in the sample shall have 4 or more coliform organisms per 100 mL, and the arithmetic mean of the coliform density of the sample shall not exceed 1

coliform organism per 100 mL.[28] We were interested not only in the potability of drinking water, but also in the purity of the water as determined by total bacterial counts in the samples. One of the reasons people choose to drink bottled water instead of tap water is because of the perceived purity of bottled water[29]; however, while two thirds of the bottled water samples had lower bacterial counts than the tap water samples (32 brands of bottled water had levels <0.01 CFU/mL), one quarter of the bottled water samples contained bacterial counts more than 10 times higher than those of the tap water samples. Similar results were noted in a survey of 103 brands of bottled water that found that at least one third had levels of bacteria and chemicals that exceeded the industry's own guidelines for purity.[30] On the other hand, the bacterial counts in the tap water samples from the 4 Cleveland water plants varied only slightly (0.2 to 2.7 CFUs/mL). Based on these results, in Cleveland, one can be assured of tap water with very low bacterial counts, while the quality of bottled water may vary greatly, with bacterial counts ranging from less than 0.01 to almost 5000 CFUs/mL.

CONCLUSIONS

Tap water in Cleveland is more effective in preventing tooth decay than 94.7% of the bottled water purchased within the same area, and is as pure or more pure than almost 22.6% of the bottled waters. Improving the quality of drinking water is a major public health initiative in the United States, and all public drinking water sources are regulated by the Environmental Protection Agency to ensure quality water. Under the new Consumer Confidence Reports: Final Rule[20] provision from the 1996 amendments to the Safe Drinking Water Act, citizens are entitled to know the quality of drinking water produced for public distribution, but the consumer's right to know does not extend to commercial bottled water at this time.

Our expectation of increased tooth decay prevention from the tap water fluoridation program is likely to be compromised by the use of alternative sources of drinking water that are low in fluoride. Additionally, there is no guarantee that either tap water or bottled water will have a low microbial content or will be free of pathogens.

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