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Optimal Fluoridation

The Concept and Its Application to Municipal Water Fluoridation

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Optimal fluoridation has been defined as that fluoride exposure which confers maximal cariostasis with minimal toxicity and its values have been previously determined to be 0.5 to 1 mg per day for infants and 1 to 1.5 mg per day for an average child.

Total fluoride ingestion and urine excretion were studied in Marin County, California, children in 1973 before municipal water fluoridation. Results showed fluoride exposure to be higher than anticipated and fulfilled previously accepted criteria for optimal fluoridation. Present and future water fluoridation plans need to be reevaluated in light of total environmental fluoride exposure.

IN THE PAST THREE DECADES, the addition of fluoride ions to municipal water supplies has been strenuously promoted by many public health officials as a public health measure to reduce the incidence of dental caries. Often these measures have been just as strenuously resisted by persons whose objections stem from questions of presumed efficacy, fears of potential fluoride toxicity and the abridgment of personal rights. Despite the passage of 30 years, the fluoride controversy swirls up anew whenever a community undertakes to enforce acceptance of fluoridation of its water supply by the process of majority vote, itself a technique quite curious and unique among public health affairs.

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During 1973, Marin County, California, residents within the boundaries of the Marin Municipal Water District (MMWD) found themselves involved for the third time in this controversy. This time, however, a new question was raised, the question of optimal fluoridation or the preexisting sufficiency of dietary fluoride intake. This resulted in intensive investigation by the local medical society—particularly its committee on environmental health, plus other interested members. The purpose of this paper is to review the nature of the problem, to define optimal fluoridation, to present the available data pertaining to fluoride intake in "unfluoridated" Marin County when its water supply contained 0.1 parts per million (ppm) of fluoride and to discuss logical inferences and their potential application.

The history of fluoridation is interesting in that its role in cariostasis devolved from research not into the problem of tooth decay but into the problem of mottled enamel. Before 1920, this conspicuous developmental hypoplastic staining of the teeth was found to be endemic in some areas of this and other countries. In 1916, a dentist, F. S. McKay of Colorado, reported this endemic phenomenon.[1] Later he became convinced this was probably associated with some unknown element in the water supply.[2] In 1931, the causative agent was identified simultaneously by two separate research groups as fluoride[3,4] and mottled enamel became known as dental fluorosis. Because of this discovery, the United States Public Health Service assigned a staff dentist, H. Trendley Dean, the task of determining the level of fluoride in water which would not cause this deleterious effect.[5] Dean was able to show that dental fluorosis became detectable when fluoride concentrations rose over 0.6 ppm and, at higher levels, the severity of mottling rose sharply until, at concentrations of 2 ppm or above, dental fluorosis became "an acute and urgent public health problem."[6] Concurrently, Dean, aware of McKay's observation that mottled teeth appeared to be relatively free of caries, gathered data which were published in 1938 and which confirmed this relationship.[7] Subsequently, Dean and other Public Health Service researchers surveyed naturally fluoridated communities in order to establish quantitatively the relationship between fluoride in drinking water and caries incidence.[5,6]

By 1942, Dean and his co-workers had concluded that maximal cariostasis occurred at a fluoride concentration of 1 ppm (1 mg per liter) at which level only 10 percent of the population was affected with the mildest degree of dental fluorosis.[6] Fluoride concentrations above 1 ppm did not confer significant additional cariostasis but did sharply increase the incidence of dental fluorosis. Consequently, in 1943 the Public Health Service established a drinking water standard of 1 ppm as the maximum allowable fluoride concentration.[8] (In 1962, a range of 0.7 to 1.2 ppm of fluoride was recommended depending inversely on temperature ranges.) During the 1940's extensive investigation established that, although fluoride is ubiquitous throughout nature, dietary intake of fluoride other than in water was essentially quite minimal.

McClure's classic summary in 1943 of daily intake of fluoride from food and drinking water sources based on estimates from existing fluoride content of specific foods, showed that in a community with drinking water containing fluoride at 1 ppm the average quantity of fluoride contained in food and water consumed by those 1 through 9 years old was 0.4 to 1.4 mg per day.[9] Of this total, only 0.03 to 0.45 mg per day were usually obtained from the dry food, the rest coming from water. These same figures appeared consistently in public health publications for the next three decades.[10-12] In all these publications, optimal fluoride intake for the appropriate age groups is calculated as 1 to 1.5 mg per day from all sources. This was reaffirmed by the Academy of Pediatrics' Committee of Nutrition in 1972.[13] In their report they state that "in the temperate zone, fluoridated community water supplies are increased in fluoride content to a level of 1.0 ppm, thus providing, on the average, a total fluoride ingestion of 1.5 mg per day." This, they state, provides the "optimum fluoride intake for the growing child," as even "an adverse effect on tooth structure may result at intake levels above 5 mg." Thus the level of optimal fluoride intake is consistently and rather firmly established.

Despite the emphasis on water, however, there is no doubt that food fluoride, except of bone meal, is essentially just as well absorbed and available as the fluoride in water.[14] Even "96 percent of the fluoride from a calcium fluoride solution was absorbed" as Hodge states. According to the World Health Organization,[15] fluoride absorption from beverages containing fluoride ions "is as complete from them as from plain water." Fluoride absorption is nearly the same whether the fluoride was supplied in milk or in water.[14,15]

Optimal fluoridation can be stated to be the average daily absorption of 1 to 1.5 mg of fluoride, regardless of source, by the age group 1 to 12. The question facing residents of Marin County, relative to this concept of optimal fluoridation, was brought into focus by the recent findings of increased dietary fluoride sources. These dietary sources occur as fluoride is incorporated into the food chain by canning, bottling or other prepreparation of food;[16,17] by industrial fluoride as an air pollutant being absorbed by broad-leaved plants such as lettuce and cabbage;[18] by fluoride-polluted forage for food animals,[19] and by numerous other direct and indirect ways which inevitably affect humans.

Marier and Rose, at Canada's National Research Council, calculated food fluoride, assuming all food processed in water at 1 ppm, and found that by 1963 food-chain fluoride was approximately 3½ times that which was found by earlier investigators.[16] Spencer and co-workers analyzed diets in the Veterans' Hospital at Hines, Illinois, and found a daily intake range of fluoride from 3.6 to 5.4 mg per day.[21] Children's cereals such as Grape-Nuts® and Wheaties®, milled in fluoridated Minneapolis, have shown the rather high fluoride values of 6.2 ppm and 10.1 ppm respectively.[22] In 1971, the United States Army Institute of Dental Research published a study of diets obtained in a "market basket" type analysis of foods collected in 1967 and 1968 by several teenage boys from supermarkets in fluoridated Baltimore.[23] Analysis of the diets included not only the foods purchased, but milk and water used in food preparation, plus beverages consumed. They were found to provide an average of 2.1 to 2.4 mg of fluoride per day. Consumption of water, per se, was not separated out of the beverage group which included soft drinks, tea, coffee and milk.

Though not a problem in Marin County, airborne fluoride can represent appreciable fluoride exposure. A 1970 publication of the United States Department of Agriculture Research Service states "airborne fluorides have caused more worldwide damage to domestic animals than any other air pollutant. . . . Whenever domestic animals exhibited fluorosis, several cases of human fluorosis were reported. . . . Man is much more sensitive than domestic animals to F [fluoride] toxicity."[20]

It should be recalled that the United States Food and Drug Administration issued a policy statement, published in 1953, which held that "fluorine intake is the same whether the fluoridated water is added in a food factory or in the home kitchen." The statement concludes that there should be appraisal of "probable fluorine intake from all sources other than the water supply."[24]

Making the natural assumption that foods sold in supermarket chain stores are the same, whether the store is in fluoridated San Francisco, for example, or in unfluoridated Marin County, the question of average daily fluoride intake by Marin children became a significant issue.

The Marin County Medical Society Environmental Health Committee opted for a direct approach to find the answer. Through Parent-Teacher Association contacts and other interested parties, a drive was made to compile, as accurately as possible, records of the food, snacks and beverages consumed in a day by an average child in the county. Eventually, 153 such day-food lists were compiled. Due to budgetary limitations, only 17 (chosen by chance lot) could be offered for fluoride analysis.

The Marin Food Fluoride Study

Design of the Study

The procedure used in the study was to obtain *duplicate* sample daily diets from Marin County children in the age groups 4 through 6, 7 through 9, 10 through 12, and 13 through 15 years of age and to submit each day's diet for individual total fluoride determination.

Duplicate meals (including school lunches and snacks) were prepared in the quantities consumed. The mothers were cautioned to duplicate only the amount each child actually had eaten, and to discard amounts equal to what the child left on the plate. Each full day's diet was placed in a fresh individual plastic container and fluids other than water were combined in milk cartons or sent along within their original containers. When poultry was part of the day's meal, the edible portions only were included, the bones discarded, similarly for meat bones, and the peels of oranges.

The individual duplicate daily diets were refrigerated overnight and delivered the next morning to a laboratory for analysis. An independent laboratory was selected from a list of laboratories regularly employed on research projects by the California State Department of Health, the State Department of Agriculture and the University of California. Each diet was homogenized, dried and analyzed using current methods of the Association of Official Analytical Chemists (AOAC). Three to four aliquots of each individual diet obtained an accuracy of 2.7 percent. The final figure is an average of aliquots (Table 1, Total Fluoride).

By fortuitous coincidence, a group of essentially pro-fluoridation dentists and pediatricians proceeded with an independent study involving urine fluoride excretion in 17 well Marin children, age 12 to 16. A report of this study was presented in testimony by a Public Health Department official to a State Board of Health meeting in Sacrament (June 1973) and made available to the press. These data indicated an excretion of fluoride in urine in the concentration range of 0.2 to 0.7 ppm in the absence of any supplemental fluoride or water fluoridation (MMWD water fluoride is approximately 0.1 ppm or less). Later in testimony before the county medical society, Public Health Department officials stated that a total of 72 specimens were analyzed and similar results found. The exact figures from this study are unavailable to the author, though the mean was given as 0.34 ppm.

Analysis of Data

Admittedly the data are derived from small sample numbers. This, in the case of the food study limitation, was determined solely by the limits of economic realities. A larger study must await a future larger financial commitment. However, the reader should be assured that the literature concerning fluoride abounds with landmark research which involves samples of even smaller numbers.[25] While the Marin study may be criticized because it was not as extensive as might be desired, it does represent the only such data existent for this area and this time set.

The rather wide range of food fluoride found—as well as the wide range of urine fluorides reported—attest to the recognized wide variability of children's diets from day to day. Conversely, the narrow range found in the San Filippo and Battistone report (representing market basket choices of four teenage boys) is quite unlikely and atypical of results from other dietary fluoride studies.[26]

Bias in reporting to favor the investigators is a recognized potential source of error in sampling techniques such as those used in the food study. However, this is minimized by the fact that mothers are unlikely to know which foods are high or low in fluoride. It is certainly no less accurate or less meaningful than "market basket" studies.

Finally, it must be noted that before our Marin data were collected, no reports of intake in an "unfluoridated" community in the United States had been published for approximately 20 years.

Reliability and accuracy of spot tests of urine fluoride concentrations are not universally accepted. However, the accuracy of the mean of 72 urine samples was strongly defended by Public

TABLE. 1—*Total Food-Borne Fluoride, 1973*

Child (family initial)	*Age*	*Body Weight* *kg.*	*lbs.*	*Complete Day's Diet (wet weight, inc. bev.) (grams)*	*Total Fluoride (milligrams)*	*Average Fluoride (per age range) (milligrams)*
C ...	5	20.9	46	1,620.1[1]*	0.900	
				1,651.6[2]	0.845	0.942
L ...	6	20.4	45	1,392.6[3]	1.062	
				1,433.9[4]	0.961	
N ...	7	29.5	65	1,124.5[5]	1.010	
C ...	7	24.5	54	1.651.6[6]	0.350	
				1,561.2[7]	0.850	1.114
C ...	9	32.7	72	1,465.0[8]	1.155	
				2,177.8[9]	2.205	
L ...	10	34.0	75	870.5[10]	0.235	
				993.1[11]	0.405	
L ...	12	47.7	105	1,124.1[12]	0.871	0.911
				2,323.3[13]	1.655	
N ...	12	59.0	130	1,773.1[14]	1.390	
C ...	14	54.5	120	2,363.0[15]	2.100	
				1,524.4[16]	1.055	1.518
G ...	14	43.2	95	..[17]†	1.400	

*Individual diets are discussed in the summary following. With some children, diets for two different days were collected.
†Weight not recorded.

INDIVIDUAL DIETS (Summary of Details)

The dietary patterns of these families had certain similarities common to many families with growing children, with convenience foods a little less than one third of the food, canned beverages used for mixing rather than fresh preparations, commercial breads and cakes.

BREAKFASTS consisted of fruits and juices, breads, protein and cereals: Cream of Wheat®, Wheaties®, granola (3, 5, 6, 14, 17), Cheerios® (3, 4, 13); bacon, sausage or other pork (7, 8, 9, 15, 16); eggs universally; and occasional pancakes, pop-ups and similar novelties.

LUNCHES were typically sandwiches with liverwurst, jack cheese, frankfurters, cold roast beef, salami or peanut butter (6, 7, 8, 15, 16); fresh fruits, apples, oranges, bananas; small commercial cakes. Diets (13) and (16) included one cup of tea each; diet (1) had half a cup of tea. Diet (7) had a tuna salad sandwich. Diets (15) and (9) had 1½ oz (Gortons®) minced clams (with juice) mixed in an 8 oz serving of Campbell's® mushroom soup. (See discussion below.)

SUPPERS included poultry (3, 5, 13, 14), lamb chop (10, 12), hamburger, ground beef or commercial specialty beef (1, 4, 8, 16, 17); roast beef, stew (2, 11), pork in various forms (6, 7, 9, 15). Seafood was missing from the supper meals. Diet (15) had a cup of tea. Cooked vegetables, potatoes, salads, ice cream for some, cake and fruit filled out the supper meals.

BEVERAGES were generally milk and skim milk, fruit juices, some Coca Cola®, and fruit-ades, hot chocolate and an occasional single cup of tea as noted.

SNACKS included jelly beans, Saltines®, milk shakes, a mayonnaise and mustard sandwich, cookies, salami, grapefruit and other fruit and small cakes.

DISCUSSION: Other than the small amounts of tea, the tuna salad sandwich, and the divided can of minced clams, sources of excess fluoride would require detailed food analyses to pinpoint.

The close readings in diets (1) and (2) (same child) which had similar volumes of food by weight, a half cup of tea (diet 1), no tea in diet (2), indicate that *volume* rather than a portion of high fluoride is more significant in determining the fluoride quantity. This is further exemplified in diet (9), in which the 1½ oz (which is a very small amount) of minced clams is also accompanied by a 50 percent greater amount of food than diet (8) (same subject, and no seafood).

The same trend is visible in diets (15) and (16), in which the small amount of minced clams also finds itself in a diet 50 percent greater by weight than the diet having no seafood (but one cup of tea in each meal, thus not a factor).

Diets (12) and (13) show a doubling of food volume and total fluoride, with one cup of tea in the larger volume diet (13).

It is very likely that in coastal regions seafood plays a more prominent role in the general diet than in inland areas. Certainly in the face of busy school schedules and as an alternative to higher priced meats, the convenience of canned tuna, sardines, clams, and the like, would seem to be a reasonable trend of our modern society.

Health officials testifying before the county medical society committee.

Comparing urine fluoride excretion with fluoride ingestion in these age groups is not an unfamiliar procedure. The relationship is expressed in the mathematical formula $U = -0.13 + 0.53 A$ where U = mg of fluoride excreted in 24 hours and A = mg of fluoride absorbed in 24 hours in young people whose bone and teeth binding sites are not yet fluoride saturated.[27] The urine test results, being reported in fluoride *concentrations,* are translated into 24-hour *amounts* by assuming a 24-hour urine volume in the expected range of 1 to 1.4 liters for this age. Using this assumption and applying the function, urine fluoride excretions are found to indicate a daily absorbed fluoride level of 1 to 2.2 mg per day with the mean, derived from the 72 urine tests, being 1.4 mg per day.

These urine-derived measurements of fluoride intake are seen to correspond remarkably closely to the food fluoride study results. The relationship among fluoride measurements in McClure's 1943 fluoridated communities, Marin's 1973 "unfluoridated" community (as found in both the food and the urine excretion studies) and the 1967-1968 Baltimore market basket food study is shown in Chart 1.

Discussion

Clearly, both studies in Marin County before water fluoridation show that Marin children ingest and absorb a quantity of fluoride which is in

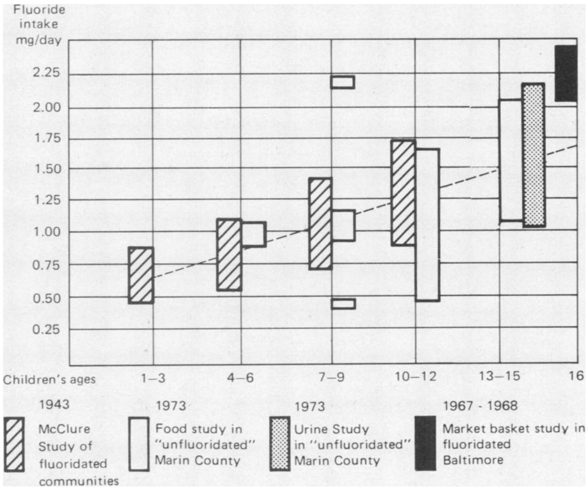

Chart 1.—Relationship of fluoride concentrations found in four studies. Broken line (---) indicates expected mean fluoride intake in an optimally fluoridated community.

the optimal range, as established and consistently enunciated by all responsible dental, pediatric and public health agencies for the past 30 years. Even without questioning the still disputed relative efficacy of fluoride in cariostasis or the philosophical argument of personal rights, it must surely be agreed that there exists no justification for exceeding optimal dosage. The acceptable range is relatively quite narrow as stated by the Committee of Nutrition of the American Academy of Pediatrics.[13] Yet it often seems to be forgotten, even by medical professionals, that fluoride is primarily a toxin.[28]

The question of whether it can, in extremely minute amounts, also be classified as a nutrient is a moot point since its ubiquity rules out any chance of an insufficient supply from that point of view.

The concept of optimal dosage, it must be reemphasized, states that beyond a given dosage no further benefits are conferred *and* toxic effects become more and more likely.

Presumably by stimulating increased water intake, warmer climates often lead to obvious endemic fluorosis, even when fluoride concentration is in respectable ranges. There is, for example, a recent report in *Lancet* by the National Institute of Nutrition, Indian Council of Medical Research, Hyderabad, India,[29] which showed endemic fluorosis in areas with fluoride levels of 3.5 ppm associated with kyphosis, exostoses, osteoporosis and a disabling genu valgum. It is of particular interest that levels of serum calcium, phosphorus and alkaline-phosphatase activity were normal.

Even in the cooler climate of Minnesota, increased water intake at conventional fluoride concentrations, under certain circumstances, has been found to be deleterious. A recent report from the Mayo Clinic[30] showed the development of osteofluorosis in two teenagers with preexisting renal disease, which obviously affected the intake and possibly the clearance of fluoride. Undoubtedly, there exist occupational and other circumstances which will greatly increase the fluid intake and thus the fluoride absorption when the available water supply is used as the carrying vehicle for fluoride.

Conclusion

Optimal fluoridation, by previously accepted standards, occurs when an average child in the formative age group receives 0.4 to 1.5 mg of fluoride per day. Seventeen sample diets of Marin children were analyzed for total fluoride content. An average daily intake of 0.9 to 1.5 mg was found.

Urine fluoride excretion by Marin children had been reported and these results are analyzed. They are found to correspond very closely to results of a study of fluoride ingestion.

By these standards, the available data suggest that Marin County was an optimally fluoridated community without the addition of supplemental water fluoridation. The decision of the State Board of Health to raise the Marin County water fluoride level from 0.1 ppm to a maximum of 1.2 ppm is difficult to reconcile with these facts.

Recognizing the limitation of our small sampling, it is clear that further large-scale studies should be accomplished as soon as possible not only in Marin County but in other communities, both fluoridated and "unfluoridated."

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