# An Update on Fluorides and Fluorosis

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## Abstract

*Decisions concerning use of fluoride in its many forms for caries prevention are more complicated now than in the past because of the need to balance these benefits with the risks of dental fluorosis. This article reviews pertinent literature concerning dental fluorosis (definition, appearance, prevalence), pre- and post-eruptive use of fluoride, esthetic perceptions of dental fluorosis, fluoride levels of beverages and foods, the Iowa Fluoride Study, and the U.S. Centers for Disease Control and Prevention's "Recommendations for Using Fluoride to Prevent and Control Dental Caries in the United States." Water fluoridation and use of fluoride dentifrice are the most efficient and cost-effective ways to prevent dental caries; other modalities should be targeted toward high-risk individuals.*

***MeSH Key Words:*** *dental caries/prevention & control; fluorides/administration & dosage; fluorosis, dental/epidemiology*

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Fluoride is still the best defence against dental caries, and fluoridation of water was recently named by the U.S. Centers for Disease Control and Prevention (CDC) as 1 of the 10 most important public health measures of the 20th century.[1] In the United States, fluoridation is probably taken for granted, because about 60% of the population is exposed to fluoridated water. However, the percentage is much lower in Canada and varies substantially across provinces. Furthermore, continuing controversies about fluoridation will probably prevent substantial expansion of such water treatment.

The history of fluoridation is a classic story of how public health should work. On the basis of the observation of a probable link between natural fluoride levels in water and caries, there was a period of controlled experimentation, followed by the broader implementation of community water fluoridation programs. Water fluoridation remains the most equitable and efficient means of delivering fluoride to the population.[2]

## Dental Fluorosis

With the substantial decline in prevalence and severity of dental caries among U.S. and Canadian children and young adults, there has been an increase in the prevalence of fluorosis.[3,4] The level of fluoride intake between the ages of about 15 and 30 months is believed to be most critical for the development of fluorosis of the most esthetically important teeth, the maxillary central incisors, but intake at younger and older ages could also be of concern.[5,6] The main documented risk factors for fluorosis (in no particular order) are fluoride in water, infant formula reconstituted with fluoridated water, supplements and dentifrice.[7–10]

Fluorosis varies in appearance from white striations to stained pitting of enamel. Fluorosis of the primary teeth occurs less often and is milder than that of the permanent teeth. Because much of the development of primary teeth occurs prenatally, fluorosis is seen primarily in the gingival third of the second primary molars.[11] Fluorosis in this location is also a strong predictor of the subsequent appearance of fluorosis in the early eruption permanent dentition (if high fluoride intake continues to about age 3).[12]

In a sectioned tooth, mild fluorosis has the appearance of a white spot lesion because of subsurface porosity.[13] With more severe forms of fluorosis, caries risk increases because of pitting and loss of the outer enamel. While some contend that it is difficult to attribute particular patterns of opacities to fluorosis, the classic appearance is characterized by banding that follows the developmental lines of the enamel and by substantial symmetry on homologous teeth.

Mild fluorosis is often not discernible. Somewhat paternalistically, the profession of dentistry decided that mild fluorosis was an acceptable tradeoff for a substantial reduction in caries. However, with esthetics becoming more important than ever, decisions concerning this tradeoff could warrant reconsideration.

## Pre- and Post-eruptive Fluoride

Fluoride is delivered topically by means of rinses, dentifrice and water. The primary means of ingestion are water and other beverages and foods, as well as dentifrice. A new emphasis describes fluoride exposures as being either "pre-eruptive" or "post-eruptive," mainly because most modalities deliver fluoride both topically and systemically (even with topical application, some fluoride is ingested, whether intentionally or not). Post-eruptive fluoride acts mainly by reducing demineralization and enhancing remineralization.

By the age of 1 year, the crowns of the first permanent molars are largely formed and those of the permanent incisors are well on their way to formation. Ingestion of fluoride before 3 to 4 years of age is critical to the possibility of fluorosis in the early erupting permanent dentition, including the maxillary incisors. Thus, the damage is very often done before young patients have their first dental visit.

Current thinking focuses more on risk assessment and individualization of fluoride therapies. It is important not to think that "more fluoride is better."[14] In the 1940s, before any fluoride products were developed, there was a reduction of 50% to 60% in caries in areas with fluoridated water relative to those without fluoridation, and fluorosis tended to appear only where water fluoride levels substantially exceeded 1 ppm. Now, with more varied and more widely available sources of fluoride, the benefit curve is flatter and the fluorosis curve is steeper.[15]

Total fluoride intake is the true risk factor for fluorosis; however, this is very difficult to quantify.[16] Fluorosis increased from the 1940s to 1980s and 1990s in both fluoridated and nonfluoridated communities. However, because various studies have used different indices of fluorosis, precise comparisons are difficult.

It is important to report the prevalence of fluorosis according to the different categories that are detected in studies and probably to make a distinction between questionable, mild and definitive forms. There is little evidence that the severity of fluorosis has been increasing in recent years.

## Esthetic Perceptions of Dental Fluorosis

There is some evidence that members of the public can be aware of even mild changes due to fluorosis and may display a preference for "normal" over mildly fluorotic teeth.[17] Until the 1990s there was very little knowledge about the public's esthetic perceptions about fluorosis, and the dental profession probably thought these perceptions were not very important.

Riordan[18] found that dentists were more perceptive of slight changes from normal appearance, probably because they are more aware of what a "normal" tooth looks like. Clark and others[19,20] found few differences among the perceptions of parents, children and dental professionals at low Tooth Surface Index of Fluorosis (TSIF) scores. Lalumandier and Rozier[21] found that, of subjects with TSIF scores of 0 (no fluorosis), 74% were somewhat or very satisfied with the colour of their teeth, whereas 26% were somewhat or very dissatisfied. Among those with a TSIF of 1 (very mild fluorosis), 11% more (total of 37%) were dissatisfied with tooth colour, and among those with a TSIF of 2 (mild fluorosis), 50% were dissatisfied.

Our studies of esthetic perceptions of dental fluorosis[17,22–24] found that members of the public had strong preferences about variations from normal tooth appearance. For example, all respondents had a preference for teeth with normal colour over teeth with mild fluorosis, whereas about two-thirds preferred the appearance of an open bite to that of moderate fluorosis. Entering dental students may be similar to lay individuals in their perceptions.[22] Interestingly, the same group of dental students assessed before entering first year and again late in their fourth year were more tolerant of many presentations of dental fluorosis, isolated opacity, and diastema after several years of dental training.[24] This change in perceptions could be because exposure to a wide variety of oral conditions during dental training leads to less concern about conditions that are not progressive disease conditions.

## Fluoride Intake

The optimal level of fluoride intake is not known with certainty. A level of 0.05–0.07 mg/kg is often thought of as "optimal"[25]; however, lower levels of intake have been associated with fluorosis. The optimal level is virtually impossible to calculate because of variations in fluoride levels in all sorts of foods and beverages. It cannot be assumed that because a person resides in a community with nonfluoridated water, he or she is receiving low levels of fluoride.[26] People can get fluoride from water at locations other than home (e.g., child care setting, school, work) or from drinking substantial amounts of soft drinks or juices, which often have fluoride levels close to the optimal range for drinking water. Conversely, just because a food manufacturing plant is situated in an area with fluoridated water does not mean that all of its products contain fluoride, as the plant could have an alternative water source.

In the United States, sources of bottled water must generally be tested for fluoride content only once per year. Most bottled waters contain less than 0.3 ppm; however, some contain close to or more than 1 ppm.[1,26,27] Some home water filtration systems (distillation and reverse osmosis) take the fluoride out of water, but the carbon/charcoal systems do not.[26,27]

Breast milk and cow's milk are very low in fluoride; however, in the 1970s some infant formulas were found to have high fluoride content.[26] U.S. manufacturers voluntarily

*Table 1* **Fluoride levels of bottled waters,[27] infant formulas,[27] infant foods,[39] juices[37] and soft drinks[38]**

| Source | No. | Fluoride level (ppm) Range | Mean (and SD) | Median |
|---|---|---|---|---|
| **Bottled water** | 78 | 0.02–1.36 | 0.18 (0.35) | 0.06 |
| **Infant formulas** | | | | |
| Ready-to-feed | 16 | 0.04–0.55 | 0.17 (0.15) | 0.16 |
| Liquid concentrate[a] | 14 | 0.04–0.19 | 0.12 (0.08) | 0.10 |
| Powder concentrate[a] | 17 | 0.05–0.28 | 0.14 (0.11) | 0.09 |
| Ready-to-eat infant foods | 206 | 0.01–8.38 | 0.35 (0.83) | 0.12 |
| **Infant dry cereals[a]** | 32 | 0.05–0.52 | 0.22 (0.13) | 0.15 |
| **Juices** | 532 | 0.02–2.80 | 0.56 (0.52) | 0.65 |
| White grape (as ingredient) | 19 | 0.15–2.80 | 1.33 (0.51) | 1.40 |
| Other grape (as ingredient) | 66 | 0.05–2.45 | 1.00 (0.65) | 0.66 |
| Other | 447 | 0.02–2.64 | 0.57 (0.50) | 0.32 |
| **Soft drinks** | 332 | 0.02–1.28 | 0.72 (0.34) | 0.79 |

*SD = standard deviation.*
[a]*Reconstituted with distilled water.*

and dramatically reduced levels of fluoride in formula by the 1980s, and lower concentrations were documented in the 1990s.[27] No recent studies have been done in Canada. In the United States, levels are higher when powdered concentrate is reconstituted with fluoridated water. Also, soy-based formulas are consistently higher in fluoride content than milk-based products. Other foods that have high fluoride content are teas, dry infant cereals, dried chicken, fish and seafood products.

Fluoride mouth rinses are generally contraindicated for young children, because preschool children cannot rinse and spit properly. There is little risk of fluorosis from ingesting fluoride through professionally applied gels, especially when adequate suction is used. Use of fluoride varnish or foam reduces ingestion further. However self-applied gels, used on a daily basis, could present a considerable risk for overingestion.[26]

There continues to be controversy concerning the use of dietary fluoride supplements, and now they are not generally recommended. In the United States, national data from the mid- to late 1980s showed that about 15% of children less than 2 years of age, 16% of those 2–4 years of age and 8% of those 5 to 17 years of age took dietary supplements, and more than 50% of children took fluoride supplements at some time.[28] Many dentists and physicians who prescribe supplements do not adequately test the child's water supplies for fluoride content, which substantially increases some patients' risk of overingestion.[29,30] Also, if the child lives in a home with low fluoride levels in the water, but drinks fluoridated water in the child care setting or at school, then fluoride supplement doses should be reduced accordingly. An additional paradox is that high-risk children are least likely to comply with a fluoride supplement regimen[31] although they would have the greatest potential to benefit.

Over 90% of dentifrices contain fluoride, usually at a concentration of 1,000 ppm. U.S. national data from the late 1980s showed that use increased from about 32% of children younger than age 2 to 91% among 4-year-olds. Studies of families with generally higher socio-economic status found that approximately 85% of children were using fluoride dentifrice by 24 months of age.[32,33] While low-fluoride toothpastes (e.g., 500 ppm) are available for children in a number of countries, they are not available in North America. Furthermore, they are unlikely to become available here, as the manufacturers would have to conduct expensive new clinical trials to gain regulatory clearance from the U.S. Food and Drug Administration, and these products would probably show reduced effectiveness in reducing caries at the lower concentrations.[34]

## The Iowa Fluoride Study

Because it is so difficult to determine the relative importance of the various sources of fluoride exposures and intake, a study was begun in Iowa in 1992 with the goal of assessing longitudinal patterns of fluoride intake and dental fluorosis and caries. This prospective cohort study enrolled about 1,400 mothers with newborns from 8 Iowa hospitals from 1992 to 1995, and about 750 of these women are still participating. In general, the mothers are well educated, and there is an even split between male and female children.[11,16,31–33,35] An expansion of the study is assessing the children's bone development.[36] Concurrently, the levels of fluoride in a large number of beverages and infant foods have been assayed, which has resulted in a number of interesting observations, including those outlined below.

*Table 2* **Distributions of estimated daily fluoride intake from water, supplements, dentifrice and combined by age (mg) (adapted from Levy and others[16])**

| Source of fluoride, by child's age (months) | No. of children | Fluoride intake (mg) | | Fluoride intake (mg), by percentile | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Minimum | 10th | 25th | 50th | 75th | 90th | Maximum |
| **Dentifrice** | | | | | | | | | | |
| 3 | 1,202 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 12 | 777 | 0.038 | 0.136 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 | 0.109 | 1.750 |
| 24 | 627 | 0.257 | 0.312 | 0.000 | 0.000 | 0.041 | 0.125 | 0.375 | 0.656 | 1.750 |
| 36 | 523 | 0.278 | 0.292 | 0.000 | 0.018 | 0.063 | 0.188 | 0.438 | 0.750 | 1.688 |
| **Supplements** | | | | | | | | | | |
| 3 | 1,193 | 0.018 | 0.060 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.042 | 0.833 |
| 12 | 794 | 0.015 | 0.054 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.013 | 0.500 |
| 24 | 646 | 0.008 | 0.052 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| 36 | 536 | 0.013 | 0.079 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| **Water** | | | | | | | | | | |
| 3 | 1,178 | 0.429 | 0.525 | 0.000 | 0.000 | 0.000 | 0.264 | 0.740 | 1.065 | 6.656 |
| 12 | 779 | 0.307 | 0.372 | 0.000 | 0.019 | 0.065 | 0.207 | 0.434 | 0.740 | 5.989 |
| 24 | 630 | 0.289 | 0.264 | 0.000 | 0.035 | 0.102 | 0.222 | 0.394 | 0.594 | 2.109 |
| 36 | 532 | 0.341 | 0.299 | 0.000 | 0.047 | 0.127 | 0.266 | 0.461 | 0.712 | 1.724 |
| **Combined** | | | | | | | | | | |
| 3 | 1,169 | 0.448 | 0.520 | 0.000 | 0.000 | 0.033 | 0.304 | 0.746 | 1.065 | 6.656 |
| 12 | 755 | 0.360 | 0.396 | 0.000 | 0.033 | 0.107 | 0.259 | 0.503 | 0.790 | 5.989 |
| 24 | 603 | 0.547 | 0.414 | 0.004 | 0.139 | 0.264 | 0.441 | 0.722 | 1.132 | 2.880 |
| 36 | 506 | 0.634 | 0.425 | 0.009 | 0.195 | 0.327 | 0.539 | 0.826 | 1.163 | 2.976 |

Soy-based formula tends to have a higher fluoride content than milk-based formula, because soy proteins bind some of the fluoride.[27] If children are getting fluoride from a lot of other sources, it might be better if they were given milk-based formula, if possible. Fluoridated water added to powdered concentrate could result in ingestion of high levels of fluoride if infants are ingesting many ounces of reconstituted formula per day. Among the bottled waters tested, 83% contained less than 0.3 ppm; however, 10% contained more than 0.7 ppm.[27] Thus, it cannot be assumed that, just because a child is consuming bottled water, the fluoride intake is low. Another finding is that the manufacturers of particular beverages change the water sources used for reconstitution over time, which could lead to variations in fluoride levels. However manufacturers are not required to document fluoride levels, so there is no way to know.

Many types of juices and juice drinks were tested,[37] and, consistent with other research, the grape juices (especially white grape juices) contained the highest fluoride levels. Overall, about 42% of the tested juices and juice drinks had fluoride levels greater than 0.6 ppm. It is especially difficult to determine the level of fluoride in soft drinks because the manufacturers operate so many bottling plants. Samples of Coca-Cola tested ranged from less than 0.1 ppm to greater than 1 ppm of fluoride.[38] The water used in the bottling operation is the key factor, not the flavour, caffeine status or format (diet vs. regular) of the beverage. Overall, about 77% of soft drinks had fluoride levels greater than 0.60 ppm.

Among solid foods, fruits consistently had low fluoride levels, meats had slightly higher levels, and chicken products for infants had the highest levels.[39] The manner in which the chicken is mechanically deboned allows fluoride-rich bone particles to be incorporated into the food. Chicken products for infants have about 20 times the level of fluoride of fruit products for infants. Just 2 ounces (about 60 g) per day of the chicken food provides about 0.5 mg fluoride, about the maximum that an infant should be receiving from all sources.

Table 1 summarizes the Iowa Fluoride Study's findings concerning fluoride levels of beverages and infant foods.[27,37–39]

Children should be supervised carefully when using fluoride dentifrice because they tend to swallow a lot of dentifrice.[34] Parental supervision should occur both during placement of dentifrice on the brush and during brushing. In a study of preschoolers, the amount swallowed was most frequently 55% to 79% of the amount of dentifrice used, but ranged as high as 90%.[33] As a general rule, children use more dentifrice when not supervised. This author recommends that children spit out the dentifrice, but not rinse, so that fluoride will continue to bathe the teeth for a period after brushing.

Use of dentifrices that have been flavoured for children (e.g., bubble gum or fruit flavour) increases children's

***Table 3*** **Summary of recommendations for using fluoride to prevent and control dental caries in the United States (adapted from CDC[1])**

**Public health and clinical practice**

1. Continue and extend fluoridation of community drinking water.
2. Counsel parents and caregivers regarding use of fluoride toothpaste by young children, especially those < 2 years of age.
3. Target mouth-rinsing to persons at high risk.
4. Judiciously prescribe fluoride supplements.
5. Apply high-concentration fluoride products to persons at high risk for dental caries.

**Self-care**

1. Know the fluoride concentration in the primary source of drinking water.
2. Use small amounts of fluoride frequently.
3. Supervise use of fluoride toothpaste among children < 6 years of age.
4. Consider additional measures for persons at high risk for dental caries.
5. Use an alternative source of water for children ≤ 8 years of age whose primary drinking water contains > 2 ppm fluoride.

**Consumer product industries and health agencies**

1. Specify the fluoride concentration of bottled water on the bottle label.
2. Promote use of small amounts of fluoride toothpaste by children < 6 years of age.
3. Develop a low-fluoride toothpaste for children < 6 years of age.
4. Collaborate to educate health care professionals and the public.

**Further research**

1. Continue metabolic studies of fluoride.
2. Identify biomarkers of fluoride.
3. Re-evaluate the method of determining the optimal fluoride concentration of community drinking water.
4. Evaluate the effect of fluoride mouth rinse, fluoride supplements and other modes of delivering fluoride on dental caries.
5. Study the current cost-effectiveness of fluoride modalities.
6. Conduct descriptive and analytical epidemiologic studies.
7. Identify effective strategies to promote adoption of recommendations for using fluoride.

acceptance of fluoride dentifrice, enhancing caries prevention. However, children's flavours have been associated with use of larger quantities of dentifrice.[40,41] A small, pea-sized amount of dentifrice is recommended; however, this expression has different meanings, which has led to recommendations that dentifrice be applied across rather than lengthwise along the brush bristles.

To estimate the amount of fluoride ingested from various sources, parents of children in the Iowa Fluoride Study were asked to complete questionnaires about water sources, use of fluoride supplements and dentifrice, and intake of beverages and selected foods.[16] It was found that 25% of the children were ingesting an estimated 0.8 mg of fluoride daily, and 10% were ingesting more than 1 mg daily. On a per-kilogram basis, 25% of the children were getting more than double the recommended 0.05 to 0.07 mg/kg. Intake of fluoride also varies considerably over the first couple of years of life. **Table 2** details the distribution of combined fluoride intake from water, supplements and dentifrice at 3, 12, 24 and 36 months of age.[16]

Approximately 12% of children in the Iowa Fluoride Study had mild fluorosis of the primary teeth, mostly on the cervical third of the second molars.[11]

## Conclusions

These findings underlie the need to prescribe fluoride on the basis of sound information about the patient. The recent "Recommendations for Using Fluoride to Prevent and Control Dental Caries in the United States" from the CDC[1] are helpful. **Table 3** summarizes the CDC recommendations.

Water and toothpaste are the mainstays of fluoride delivery for all. Other modalities should be considered only if the child is at high risk for caries. Care should be exercised in prescribing other modalities of fluoride delivery before age 6, and especially before age 3, because of the risk of dental fluorosis.

High-risk groups include children of low socioeconomic status, those whose parents have low levels of education, those who do not regularly attend for dental care and those without dental insurance. High-risk children are those with active caries; those whose siblings have high levels of caries; those with high levels of *Streptococcus mutans*, cognitive or physical challenges to oral hygiene, or low salivary flow or buffering capacity; and especially those consuming a cariogenic diet and receiving inadequate exposure to fluoride.

The most important messages about fluoride recommendations are that making them is more difficult than it used to be and that "more fluoride is not necessarily better." ◆

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Comment Aust Dent J, 42 (4), 268-9 Aug 1997

# Fluoride Concentration in AgF and Dental Fluorosis

D C Neesham

PMID: 9316315

## Comment on

Unacceptably High Levels of Fluoride in Commercial Preparations of Silver Fluoride

T Gotjamanos et al. Aust Dent J 42 (1), 52-3. Feb 1997. PMID 9078648.

Instead of expected fluoride ion concentrations of around 60,000 ppm, commercial preparations of 40 per cent aqueous silver fluoride were found to contain 120,000-127,000 ...

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