REVIEW & COMMENTARY

# Fluoride Intake and Prevalence of Dental Fluorosis: Trends in Fluoride Intake with Special Attention to Infants

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## Abstract

***Background:*** *Although the predominant beneficial effect of fluoride occurs locally in the mouth, the adverse effect, dental fluorosis, occurs by the systemic route. The caries attack rate in industrialized countries, including the United States and Canada, has decreased dramatically over the past 40 years. However, the prevalence of dental fluorosis in the United States has increased during the last 30 years both in communities with fluoridated water and in communities with nonfluoridated water. Dental fluorosis is closely associated with fluoride intake during the period of tooth development.* ***Methods:*** *We reviewed the major changes in infant feeding practices that have occurred since 1930 and the changes in fluoride intakes by infants and young children associated with changes in feeding practices.* ***Results and Conclusions:*** *Based on this review, we conclude that fluoride intakes of infants and children have shown a rather steady increase since 1930, are likely to continue to increase, and will be associated with further increase in the prevalence of enamel fluorosis unless intervention measures are instituted.* ***Recommendations:*** *We believe the most important measures that should be undertaken are (1) use, when feasible, of water low in fluoride for dilution of infant formulas; (2) adult supervision of toothbrushing by children younger than 5 years of age; and (3) changes in recommendations for administration of fluoride supplements so that such supplements are not given to infants and more stringent criteria are applied for administration to children.*


*Key Words: dental fluorosis, fluoride supplements, fluoridated dentifrices, formula fluoride. [J Public Health Dent 2000;60(3):131-9]*

Current evidence suggests that the predominant beneficial effects of fluoride occur locally at the tooth surface, and that systemic (preeruptive) effects are of much less importance (1-5). Because fluoride intake at intervals throughout the day is an important factor in limiting the prevalence and severity of dental caries in erupted teeth, fluoridation of community drinking water has been and continues to be a useful public health measure. In addition, the widespread use of fluoridated dentifrices has provided effective topical application of fluoride to erupted teeth.

Although the predominant beneficial effect of fluoride occurs locally in the mouth, the adverse effect, dental fluorosis, occurs by the systemic route. From the beginning of tooth formation until tooth eruption, fluoride appears able to exert an adverse effect on dental enamel at a number of developmental stages (6,7). Of the several mechanisms proposed for the adverse effect on tooth development, the most likely is that fluoride has an effect on cell function, either through interactions with the developing ameloblasts or the intracellular matrix (8). Dental fluorosis is characterized by an increasing porosity (hypomineralization) of the subsurface enamel, causing the enamel to appear opaque. The clinical features include changes ranging from barely discernible fine white lines running across the teeth to entirely chalky white teeth (8). In advanced stages, the enamel may become so porous that the outer layers break down and the exposed porous subsurface becomes discolored.

The caries attack rate in industrialized countries, including the United States and Canada, has decreased dramatically over the past 40 years (9). On the other hand, based on changes in the earlier community fluorosis index and in the more recent index of Thylstrup and Fejerskov (10), the prevalence of dental fluorosis in the United States has increased during the last 30 years, both in communities with fluoridated water and in communities with nonfluoridated water (1,11-18).

Because dental fluorosis is closely associated with fluoride intake during the period of tooth development (19), we reasoned that a review of trends in fluoride intake over the past 70 years would be useful in predicting future trends in dental fluorosis. Thus, the purpose of this communication is to review trends since 1930 in fluoride intakes by infants and young children. We shall put particular emphasis on review of data on fluoride intake by infants because major changes in infant feeding practices over the past 70 years have been associated with age-related changes in fluoride intake, and we believe that these changes have not been generally recognized.

## General Considerations

Because the beneficial action of fluoride in caries prevention is a local effect within the mouth, the exposure to fluoride throughout the life span is a major factor in prevention of dental caries, and, if a choice is to be made between decreasing incidence of dental caries and increasing incidence of

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mild dental fluorosis, the increase in mild dental fluorosis is, from the public health point of view, a reasonable price to pay. Dental fluorosis in its mild form is merely a cosmetic disorder of no importance to health. However, if the prevalence of mild fluorosis increases in the population, it seems likely that moderate fluorosis will increase also. With appropriate intervention measures, it may be possible to continue the downward trend in prevalence of dental caries while arresting the increase in prevalence of dental fluorosis.

During the years when the predominant fluoride intake of the population was from fluoridated water, it was observed that even in areas where intake of fluoride from water was low, some level of dental fluorosis was present, and that there was a linear dose-response relationship (19). In our attempts to decrease the prevalence and severity of dental fluorosis, we need to focus on this dose-response relationship.

Fluorosis is less prevalent and less apparent in primary teeth than in permanent teeth, and, in any case, fluorosis of the primary teeth has only short-term rather than long-term consequences. Therefore, the major concern about fluorosis relates to the permanent teeth and especially to the incisors, particularly the maxillary incisors, because they are of greatest cosmetic importance. The incisors erupt by 9 years of age (20) and are by then nonsusceptible to the effects of fluorosis. In fact, the susceptibility of the maxillary incisors to fluorosis appears to be low after about 5 years of age (21). It is therefore evident that efforts at prevention of enamel fluorosis must include vigorous attention to exposure during the first 5 years of life.

Considerable evidence is now available that fluoride consumption during infancy may be an overriding factor in the development of dental fluorosis of the permanent teeth. A study of 12- and 13-year-old children who had lived since birth in a Swedish city with fluoride concentration in the drinking water of 1.2 mg/L demonstrated that enamel fluorosis was more prevalent in those who during the first 4 months of life had been fed powdered infant formulas diluted with the local water supply than in those who had been breast fed (22). Similarly, in the United States, Walton and Messer (23) found that enamel fluorosis was less prevalent in the permanent teeth of 7- to 12-year-old children who had been breast fed during the first 3 months of life than in those who had been formula fed from birth or had been breast fed for less than 3 months. More recently, Pendrys et al. (24) demonstrated that the Fluorosis Risk Index (FRI) for classification I tooth surfaces (primarily those of the incisors) was significantly greater in children who as infants were primarily fed milk-based infant formulas than in those who were breast fed or fed cow's milk. Although the association between formula consumption and dental fluorosis of the classification I tooth surfaces in a subsequent study by Pendrys and Katz (25) was not significant, this association was based only on the type of feeding experienced between 9 and 12 months of age and was unlikely to reflect the extent of formula feeding during most of infancy. Thus, several studies indicate that fluoride intake during infancy cannot be ignored in the pathogenesis of dental fluorosis of the permanent teeth.

Dental fluorosis of the permanent teeth is most commonly determined in cohorts of children from 11 to 13 years of age—those whose permanent teeth (except for the third molars) have fully erupted. To interpret data on dental fluorosis in relation to the possible impact of fluoride consumption during infancy, it is therefore necessary to relate the findings to fluoride exposure 11 to 13 years earlier. Although infant feeding practices have varied considerably, we shall demonstrate that there has been a general trend toward increasing fluoride exposure of infants from the 1930s to the present.

In reviewing data on fluoride intake by infants and children, it is, of course, necessary to be aware that fluoride intake is only roughly proportional to fluoride absorption. The major inhibitor of fluoride absorption is calcium (26,27), and the data to be presented will indicate that calcium intakes by

**TABLE 1**
**Fluoride Concentrations of Infant Foods***

| Food | F Concentration (μg/L)† |
|---|---|
| Human milk | 5–10 |
| Cow's milk | 30–60 |
| Evaporated cow's milk | 60–120 |
| Infant formulas | |
| Powdered | |
| Milk-based | 400–1,000 |
| Isolated soy protein-based | 1,000–1,600 |
| Concentrated liquid | |
| Milk-based | 100–300 |
| Isolated soy protein-based | 100–400 |
| Ready to feed | 100–300 |
| Beikost | |
| Dry cereals | |
| Produced with nonfluoridated water | 90–200 |
| Produced with fluoridated water | 4,000–6,000 |
| Wet-pack cereal-fruit products | 2,000–3,000 |
| Fruit juices | |
| Produced with nonfluoridated water | 10–200 |
| Produced with fluoridated water | 100–1,700 |
| Poultry-containing products | 100–5,000 |
| Most other products | 100–300 |

*Most reported values fall within the ranges listed in the table. Human milk from refs. 33-35. Cow's milk from Ekstrand (unpublished). Formulas from refs. 38-40. Beikost from refs. 42, 43.
†Concentrations of powdered formulas and dry cereals μg/kg rather than μg/L; concentrations have been rounded off.

infants are less now than in the 1930s to 1960s. In addition, the considerable increase in consumption of soft drinks and fruit juices by children during the past 20 years has been associated with decreased milk consumption and a consequent decrease in calcium intake. Thus, bioavailability of fluoride in the diets of infants and children is probably greater now than before.

## Fluoride Intakes by Infants

Fluoride intakes by infants are best discussed in the context of estimates of intakes required to produce adverse effects on the permanent teeth. Such estimates range from 40 to 100 $\mu g \cdot kg^{-1} \cdot d^{-1}$ (22,28-30). Although we must rely on these estimates until better estimates are available, confidence in them is limited because they (1) are based on few data, (2) fail to distinguish between doses of fluoride that result in high peak plasma fluoride concentrations (as occurs with consumption of a supplement) and those that result in lower and more sustained plasma concentrations (as occurs with consumption of infant formulas), and (3) fail to indicate the duration of time over which the intakes must be sustained to produce adverse effects.

**Major Sources of Fluoride in Infant's Diet.** *Human Milk and Cow's Milk.* Fluoride is poorly transported from plasma to milk (31-33), and concentrations of fluoride in human milk remain low, generally 5 to 10 $\mu g/L$ (Table 1) even when intakes of fluoride by the mother are high (33-35). Because of the low concentrations of fluoride in human milk, intakes of fluoride by exclusively breast-fed infants are generally extremely low, averaging about 1 $\mu g \cdot kg^{-1} \cdot d^{-1}$ (Table 2). However, at least at present (Boettcher JA, personal communication, 1998, Mead Johnson Nutritionals, Evansville, IN), and probably since the 1950s, many breast-fed infants are given at least one formula feeding daily. Fluoride intakes by these infants will be discussed in a subsequent section of this paper.

Concentrations of fluoride in milks of other mammals also are low, but, at least in the case of cow's milk, increase slightly by the time they reach the retail market. Typical concentrations of fresh fluid cow's milk available for purchase range from 30 to 60 $\mu g/L$ (Table 1) (Ekstrand, unpublished observation). Fluoride intake by an infant fed 0.15 $L \cdot kg^{-1} \cdot d^{-1}$ of cow's milk is likely to be 4.5 to 9.0 $\mu g \cdot kg^{-1} \cdot d^{-1}$ (the value is rounded off to 6 $\mu g \cdot kg^{-1} \cdot d^{-1}$ Table 2).

*Evaporated Milk Formulas.* From the 1930s through the early 1950s, most infants who were not breast fed were fed formulas prepared from evaporated milk, water, and added carbohydrate. The fluoride concentration of evaporated milk is about twice that of commercially available fresh cow's milk—60 to 120 $\mu g/L$ (Table 1). Formulas were commonly made with 0.39 L (13 fl oz) of evaporated milk and 0.57 L (19 fl oz) of water. Because the fluo-

**TABLE 2**
**Estimated Fluoride Intakes from Milks and Formulas**

| Milk/Formula | Fluoride Concentration ($\mu g/L$) Concentrate | Water | As Fed | Fluoride Intake ($\mu g \cdot kg^{-1} \cdot d^{-1}$)* Vol. of Intake $0.17\ L \cdot kg^{-1} \cdot d^{-1}$ | Vol. of Intake $0.15\ L \cdot kg^{-1} \cdot d^{-1}$ | Vol. of Intake $0.12\ L \cdot kg^{-1} \cdot d^{-1}$ |
|---|---|---|---|---|---|---|
| Human milk | | | 6 | 1 | 1 | 1 |
| Cow's milk | | | 40 | 7 | 6 | 5 |
| Home-prepared evaporated milk formula† | 90 | 200 | 155 | 26 | 23 | 19 |
| | 90 | 1,000 | 632 | 107 | 95 | 76 |
| Commercially prepared formulas‡ | | | | | | |
| Powdered | | | | | | |
| Milk-based | 690¶ | 200 | 262§ | 45 | 39 | 31 |
| | 690¶ | 1,000 | 966§ | 164 | 145 | 116 |
| Concentrated liquid | | | | | | |
| Milk-based | 200 | 200 | 200 | 34 | 30 | 24 |
| | 200 | 1,000 | 600 | 102 | 90 | 72 |
| Isolated soy protein-based | 250 | 200 | 225 | 38 | 34 | 27 |
| | 250 | 1,000 | 625 | 105 | 94 | 75 |
| Ready to feed | | | | | | |
| Milk-based | — | — | 200 | 34 | 30 | 24 |

*Mean energy intakes are approximately 114 $kcal \cdot kg^{-1} \cdot d^{-1}$ from birth to 2 months of age and 98 $kcal \cdot kg^{-1} \cdot d^{-1}$ from 2 to 4 months of age (41). An exclusively formula-fed infant consuming a 667 kcal/L formula will therefore consume approximately 0.17 $L \cdot kg^{-1} \cdot d^{-1}$ from birth to 2 months of age and approximately 0.15 $L \cdot kg^{-1} \cdot d^{-1}$ from 2 to 4 months of age. 0.12 $L \cdot kg^{-1} \cdot d^{-1}$ is an estimate of formula intake by older infants.

†Assumes 0.39 L of evaporated milk to 0.57 L of water. The designation "evaporated milk formula" includes, for convenience, similar formulas made from fresh cow's milk.

‡Values are for milk-based formulas. As may be calculated from the data in Table 1, fluoride concentrations are somewhat greater in isolated soy protein-based formulas.

¶$\mu g/kg$ formula powder.

§Assumes that 125 g formula powder diluted with 0.88 L of water makes 1 L of formula as fed.

ride concentration of evaporated milk is low, the fluoride content of evaporated milk formulas is determined primarily by the quantity of water used in formula preparation and the fluoride content of the water. A representative value for the fluoride content of an evaporated milk formula made with nonfluoridated water is 155 μg/L and that of an evaporated milk formula made with fluoridated water is 632 μg/L (Table 2). An infant fed an evaporated milk formula with fluoride content of 155 μg/L and formula intake of 0.15 L $kg^{-1} \cdot d^{-1}$ will consume 23 $\mu g \cdot kg^{-1} \cdot d^{-1}$ of fluoride (Table 2). The corresponding fluoride intake by an infant fed an evaporated milk formula with fluoride concentration of 632 μg/L is 95 $\mu g \cdot kg^{-1} \cdot d^{-1}$.

From the 1930s through the 1950s formulas prepared from fresh fluid milk with a ratio of milk solids to water similar to that of the evaporated milk formulas were also fed. Although somewhat less water was used in preparation of these formulas than of evaporated milk formulas, we have, for convenience, included these formulas under the designation "evaporated milk formulas."

*Commercially Prepared Formulas.* During the early 1950s there was a gradual shift from evaporated milk formulas to commercially prepared formulas, and by the mid 1960s commercially prepared formulas had largely replaced those made from evaporated milk (37). Although commercially prepared infant formulas are now available as powders, as concentrated liquids (1,333 kcal/L), or ready-to-feed (667 kcal/L), initially these formulas were marketed exclusively as powders. Fluoride content of these infant formulas are presented in Table 1 (38-40). Fluoride intake of an infant consuming 0.15 $L \cdot kg^{-1} \cdot d^{-1}$ of a powdered milk-based formula is approximately 39 $\mu g \cdot kg^{-1} \cdot d^{-1}$ if the fluoride concentration of the water used for dilution is 200 μg/L and 145 $\mu g \cdot kg^{-1} \cdot d^{-1}$ if the fluoride concentration of the water used for dilution is 1000 μg/L (Table 2). For the partially breast-fed infant who receives one or two formula feedings daily made from powder diluted with fluoridated water, the intake of fluoride may be appreciable. For example, two feedings of 150 ml each results in an intake of 290 μg of fluoride, or 48 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for a 6 kg infant.

Concentrated liquid formulas merely require the purchaser to add an equal volume of water before feeding the product to the infant. Before dilution with water, fluoride concentrations generally range from 100 to 300 μg/L in concentrated liquid milk-based formulas and from 100 to 400 μg/L in concentrated liquid isolated soy protein-based formulas (Table 1). Because the fluoride concentration is greater in isolated soy protein-based than in milk-based formulas, fluoride intakes are slightly greater by infants fed isolated soy protein-based formulas. Depending on the fluoride content of the water used for diluting the concentrated liquid formulas, fluoride content of milk-based formulas as fed commonly ranges from 200 to 600 μg/L (Table 2). A breast-fed infant receiving two feedings of 150 ml of a milk-based concentrated liquid formula diluted with fluoridated water would receive 180 μg of fluoride from the formula or 30 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for a 6 kg infant. Fluoride concentrations of ready-to-feed formulas are relatively low, generally 100 to 300 μg/L.

The fluoride concentration of commercially prepared infant formulas in the United States was not always as well defined as is indicated in Table 1. Until 1979, formulas marketed as liquids were commercially prepared with the local water supply (41). When the same formula was manufactured in a number of locations, the fluoride concentration of a ready-to-feed formula produced in a plant using fluoridated water ranged widely, but most commonly from 600 to 800 μg/L (42). When produced in communities with fluoridated water, the mean fluoride concentration of concentrated liquid formulas in the United States (42) and Canada (43) averaged about 600 μg/L, although somewhat greater concentrations were reported by Wiatrowski et al. (44). By contrast, the fluoride content of the same formulas made in plants with low fluoride content of the water was similar to the values listed in Table 1. In 1979 manufacturers of infant formulas in the United States and Canada agreed to use only water low in fluoride content in the manufacture of infant formulas (45). At present, when infant formulas are produced in cities with fluoridated municipal water supplies, a major part of the fluoride is removed from the water before incorporating it into infant formula.

*Beikost.* The first foods other than milk or formula commonly fed to infants are dry cereals ("infant cereals") diluted with milk or formula. These cereals are prepared by the manufacturer as a slurry and subsequently dried; thus, the fluoride content of dry cereals as marketed is influenced by the fluoride content of the local water supply used in their preparation. When produced with fluoridated water, the fluoride concentration may be 4,000 to 6,000 μg/kg (Table 1). However, the quantity of dry cereal consumed at a feeding is quite small (e.g., the quantity consumed by a 5-month-old infant is about 10 g of dry cereal in a 70 g serving). Consumption of 10 g of a cereal providing 5 mg of fluoride per kg of cereal results in an intake of 50 μg of fluoride (7 μg/kg for a 7 kg infant). Although fruit juices marketed for infants vary widely in fluoride concentration, most do not contain large amounts of fluoride and probably contribute relatively little to total fluoride intake. Strained poultry products are prepared with the bone-poor fraction of mechanically deboned chicken or turkey and the fluoride present in comminuted bone contributes to the fluoride content of the product, with concentrations sometimes as high as 5,000 μg/kg of product (Table 1); however, few infants consume these products regularly. Products other than dry cereals, fruit juices, and poultry products are generally low in fluoride and it seems likely that the fluoride intake from beikost rarely averages more than 20 $\mu g \cdot kg^{-1} \cdot d^{-1}$.

A possibly medically important beikost item in the contribution of fluoride to the infant's diet in the 1930s and 1940s was infant cereals. Pablum (Mead Johnson), a popular infant cereal, contained 0.78 percent calcium, added primarily in the form of beef bone meal (Burns RA,. personal communication, 1998, Mead Johnson Nutritionals, Evansville, IN). The mean ratio of fluoride to calcium in mechanically deboned beef in the Midwest (presumably the same as in beef bone meal produced in the Midwest) is 4 μg/mg (46). A 7 kg infant might consume 10 g of Pablum (diluted with 60 g of milk or formula) once or twice daily. One serving of Pablum would

**TABLE 3**

**Estimated Infant Consumption of Liquid Foods by Decade and Percent of Infant Days with Fluoride Intake ≥70 $\mu g \cdot kg^{-1} \cdot d^{-1}$**

| | Feedings as % of Infant Days | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fed Commercially Prepared Formula | | | | | |
| Decade | (1) Breast Fed | (2) Fed Evap. Milk Formula | (3) Powder or Concentrated Liquid | (4) Ready-to-Feed | (5) Fed Cow's Milk | (2)+(3) | Fluoridated Water* | High F Intake† |
| Birth–4 mos‡ | | | | | | | | |
| 1930–40 | 40 | 60 | — | — | — | 60 | 4 | 2 |
| 1940–50 | 30 | 65 | 5 | — | — | 70 | 4 | 3 |
| 1950–60 | 22 | 36 | 37 | — | 5 | 73 | 22 | 16 |
| 1960–70 | 14 | 20 | 46 | 5 | 15 | 66 | 41 | 27 |
| 1970–80 | 28 | — | 39 | 8 | 25 | 47¶ | 48 | 23 |
| 1980–90 | 39 | — | 50 | 11 | — | 50 | 53 | 27 |
| 1990–98 | 42 | — | 50 | 8 | — | 50 | 56 | 28 |
| 4–12 mos | | | | | | | | |
| 1930–40 | 20 | 75 | — | — | 5 | 75 | 4 | 3 |
| 1940–50 | 15 | 70 | 7 | — | 8 | 77 | 4 | 3 |
| 1950–60 | 12 | 40 | 28 | — | 20 | 68 | 22 | 9 |
| 1960–70 | 7 | 5 | 38 | — | 50 | 43 | 41 | 18 |
| 1970–80 | 14 | — | 40 | 4 | 42 | 44¶ | 48 | 21 |
| 1980–90 | 18 | — | 52 | 5 | 25 | 52 | 53 | 28 |
| 1990–98 | 20 | — | 59 | 5 | 16 | 59 | 56 | 33 |

*Percent of individuals in the United States consuming fluoridated water.
†Percent of infant days with fluoride intake ≥70 $\mu g \cdot kg^{-1} \cdot d^{-1}$.
‡A day on which an infant receives a specified feeding is one infant day. The number of infant days for infants younger than 4 months of age is 122 days times the number of infants in the cohort.
¶Includes ready-to-feed.

provide 78 mg of calcium and 312 µg of fluoride, amounting to a fluoride intake of 45 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for a 7 kg infant. By 1954 bone meal was no longer used in the manufacture of Pablum (Ryan A, personal communication, Ross Products Division, 1998) and probably not in the manufacture of other cereals.

*Supplements.* From 1972 to 1979 the Committee on Nutrition of the American Academy of Pediatrics (AAP) recommended a fluoride supplement of 0.5 mg/d for all infants living in areas with low concentrations of fluoride in the drinking water (47). The addition of a daily dose of 0.5 mg of fluoride increases fluoride consumption of a 4 kg infant by 125 $\mu g \cdot kg^{-1} \cdot d^{-1}$, and increases fluoride consumption of a 10 kg infant by 50 $\mu g \cdot kg^{-1} \cdot d^{-1}$. In 1979 the recommended dosage level for a fluoride supplement was decreased to 0.25 mg/d for all breast-fed infants and for formula-fed infants living in areas with <0.3 ppm fluoride in the drinking water, and to no supplement for formula-fed infants living in areas with more than 0.3 ppm in the drinking water (48,49). In 1995 the AAP recommended that no fluoride supplements be given during the first six months of life (50).

**Effect of Changes in Feeding Practices on Fluoride Intake by Infants.** Because infant feeding practices have undergone major changes over the past 70 years, knowledge of current feeding practices is of limited usefulness in evaluating reports concerning individuals who were born many years ago. We shall review trends in infant feeding since the 1930s and relate these to fluoride intakes by infants.

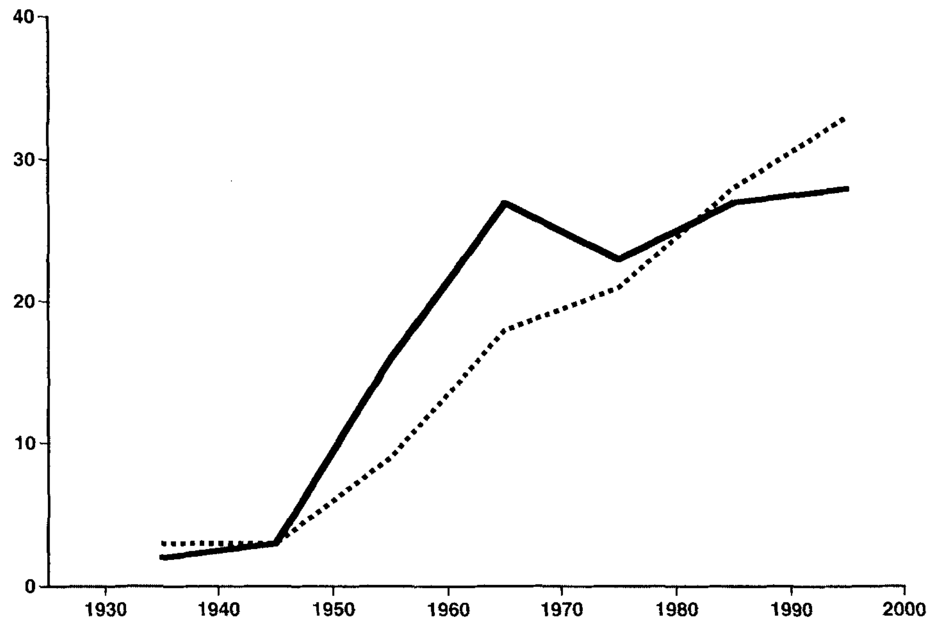
*Fluoride Intake in Relation to Type of Feeding.* With respect to the liquid food consumed by infants in the United States in the past 70 years, nearly all infants fall into one of the following categories: (1) exclusively or predominantly breast fed, (2) exclusively or predominantly fed evaporated milk formulas, (3) exclusively or predominantly fed commercially prepared powdered or concentrated liquid infant formulas, (4) exclusively or predominantly fed commercially prepared ready-to-feed infant formulas, or (5) exclusively or predominantly fed cow's milk.

If we examine these five classifications of feeding types in relation to those providing intakes of fluoride greater or less than 70 $\mu g \cdot kg^{-1} \cdot d^{-1}$ (the midpoint of the range of 40 to 100 $\mu g \cdot kg^{-1} \cdot d^{-1}$ believed to be associated with an increased risk of fluorosis of the permanent teeth), fluoride intakes will generally be less than 70 $\mu g \cdot kg^{-1} \cdot d^{-1}$ in infants in categories 1, 4, and 5 and will often be 70 $\mu g \cdot kg^{-1} \cdot d^{-1}$ or more in infants in categories 2 and 3. An exception already noted concerns infants fed ready-to-feed formulas before 1979. The proportion of infants in categories 2 and 3—i.e., those fed evaporated milk formulas or commercially prepared powdered or concentrated liquid formulas who have fluoride intakes of 70 μg · kg$^{-1}$ · d$^{-1}$ or more—is the same as the proportion of individuals living in communities with fluoridated water.

In Table 3 we have presented our estimates for the percent of infant days (i.e., each infant receiving a designated feeding for one day contributes one infant day) accounted for by the various categories of infant feeding. These estimates are presented for each decade from 1930–40 through the incomplete decade 1990–98. The percent of infant days attributed to the various feeding categories is based on previously summarized data on infant feeding practices (37) and personal communications regarding more recent market research data (Boettcher JA, perconal communication, 1998, Meadn Johnson Nutritionals, Evansville, IN; Ryan A, personal communication, 1998, Ross Products Division).

In addition, we have included in Table 3 a column giving the estimated percentage of the US population consuming fluoridated water during each decade. Although we have not located reliable data on the percent of the population consuming water with natural fluoride content of 0.7 mg/L or more from 1930 to 1945, approximately 4 percent of the population consumed such water in 1957 and in 1970 (51). We have accepted the value of 4 percent for the years 1930 to 1945. Beginning in 1945, increasing numbers of communities began to add fluoride to the water supply (52). In 1950 1.6 million persons were consuming water with adjusted fluoride content (53), or about 1 percent of the population of 151 million. We estimate that in 1950, 5 percent of the population was consuming fluoridated water (1% naturally fluoridated and 4% added). The Division of Dental Public Health (54) reported that 40.3 million people were consuming fluoridated water (naturally or adjusted) in 1957, amounting to 23.7 percent of the population of approximately 170 million. According to the Fluoridation Fact Sheet (51), the following percentages of the population consumed fluoridated water in various subsequent years: 1963, 28.2 percent; 1965, 35.2 percent; 1970, 45.3 percent; 1975, 49.4 percent; 1980, 50.5 percent; 1989, 54.5 percent; 1992, 55.9 percent.

**FIGURE 1**
**Fluoride Intakes of ≥70 μg · kg$^{-1}$ · d$^{-1}$ or more (expressed as % of days of infant feeding for infants >4 months of age [solid line] and those 4–12 months of age [dotted line] during each decade beginning with 1930)**




The values entered in Table 3 were obtained by averaging the percentage value for the beginning and end of each complete decade (interpolating when necessary to obtain the needed value) and rounding off to the nearest whole number. For the years 1990 through 1997, the 1992 value of 56 percent was used.

The final column in Table 3 presents the percent of infant days in which fluoride intake from beverage was estimated to be 70 μg · kg$^{-1}$ · d$^{-1}$ or more. The value for each decade was calculated as the product of (1) the percent of infants fed evaporated milk formulas or commercially prepared formulas prepared by dilution of powdered or concentrated liquid products (with the addition for 1970–80 of ready-to-feed formulas) and (2) the estimated percent of the population consuming fluoridated water.

As summarized in Figure 1, a steady increase in fluoride intake from beverages has occurred since 1930. With the exception of infants regularly consuming fluoride supplements and, possibly, the contribution of infant cereals to fluoride intake during the 1930s and 1940s, the fluoride intake by infants from sources other than beverages is relatively unimportant.

*Fluoride Intake from Fluoride Supplements.* In 1989 16.1 percent of infants received fluoride supplements, and it seems likely that an appreciable fraction of these infants lived in areas with fluoridated water (55). For example, in 1990 in Iowa City, IA, which has a fluoridated water supply, the percentage of infants receiving fluoride supplements was reported to be 25 percent at age 6 weeks, 19 percent at 3 months old, 23 percent at 6 months, and 23 percent at 9 months (56). In view of the newer recommendations for use of fluoride supplements—i.e., no supplements for infants younger than 6 months of age and no more than 0.25 mg/d for any infant (50,57)—fluoride intake by infants from supplements may be less in the future than in the past. Nevertheless, it would appear that fluoride supplements in the past may have made a substantial contribution to total fluoride intake of perhaps 15 percent to 20 percent of infants.

### Fluoride Intakes by Children from 1 to 7 Years of Age

At present, the major sources of fluoride intake after 1 year of age are fluoridated drinking water, fluoridated dentifrices, soft drinks, fruit juices, and fluoride supplements. Tea is regularly consumed by a minority of children in the United States, and because of its high fluoride concentration (commonly 3 mg/L), can contribute substantially to the fluoride intakes of these children (58,59). However, because we believe that the number of children who regularly consume tea is small, we have ignored tea drinking in our calculations.

**Major Current Sources of Fluoride Intake by Children.** *Fluoridated Water.* As already noted, at present more than half the population of the United States consumes fluoridated drinking water. A child consuming 0.06 L $kg^{-1} \cdot d^{-1}$ of water providing 1 mg of fluoride per liter will obtain 60 $\mu g \cdot kg^{-1} \cdot d^{-1}$ of fluoride. However, for children in the United States, drinking water no longer serves as the predominant source of fluid intake.

*Soft Drinks and Fruit Juices.* Soft drinks (carbonated beverages and ades) and fruit juices are produced with water from the community water supply and therefore many of these beverages provide generous amounts of fluoride. The mean fluoride concentration of fruit juices has been reported to be 0.6 mg/L, with concentrations above 0.6 mg/L in 43 percent of juices and concentrations above 1 mg/L in 19 percent (60); the fluoride concentration of soft drinks is similar to that of the local water supply of the community in which the beverage is produced. Reports concerning concentrations of fluoride in fruit juices and soft drinks have been identified by Levy et al. (61). For children living in communities with fluoridated water, substitution of fruit juices and soft drinks for a portion of the intake of drinking water will decrease the intake of fluoride from beverages, whereas for children living in communities with nonfluoridated water, substitution of soft drinks and fruit juices for a portion of the intake of drinking water will increase the intake of fluoride from beverages. Several studies have indicated that a substantial percentage of beverage intake by preschool children is obtained from soft drinks and fruit juices.

Data from the Continuing Survey of Food Intakes by Individuals indicate that the mean intake of carbonated beverages by 4- and 5-year-old children was 69 g in 1985 and 107 in 1986 (62). In this age group, 28.0 percent consumed carbonated beverages in 1985 and 35.4 percent in 1986, resulting in a mean intake by consumers of 243 g in 1985 and 405 g in 1986. Corresponding data for consumption of fruit drinks and ades were mean intakes of 80 g in 1985 and also in 1986, and consumption by 25.8 percent of the children in 1985 and by 32.2 percent of the children in 1986, resulting in mean intakes by consumers of 310 g and 248 g, respectively. For the years 1989–91 and 1994–96 data from the Continuing Survey of Food Intakes of Individuals are available for 3- to 5-year-old children rather than for 4- and 5-year-old children (63,64). Mean intakes of carbonated beverages were 90 g in 1989–91 and 105 g in 1994–96, with consumption by 48.2 percent of children in this age group in 1989–91 and by 36.6 percent in 1994–96. Thus, mean intakes of carbonated beverages by consumers were 187 g and 287 g, respectively. For fruit juices and ades, intakes for the two time periods were 81 g and 142 g, with consumption by 41.0 percent and 43.0 percent, resulting in mean intakes by consumers of 197 g and 352 g. Much higher intakes of soft drinks and fruit juices were reported for 4- through 6-year-old children living in North Carolina in the spring of 1990 (65). Three-day diet diaries indicated that a mean of 36.2 percent of fluid intake of these children was obtained from milk and water, with the remainder primarily from soft drinks and fruit juices.

*Fluoridated Dentifrices.* Most dentifrices now contain fluoride, generally 1 mg of fluoride per g of dentifrice. In children younger than 6 years of age, the mean quantity of dentifrice applied to the toothbrush is about 0.55 g per brushing episode (66), corresponding to a fluoride exposure of about 0.55 mg per brushing episode. An average of 48 percent of this amount is ingested by 2- to 3-year-olds, 42 percent by 4-year-olds and 34 percent by 5-year-olds (66-69). Assuming mean body weights of 15 kg, 18 kg, and 20 kg, respectively, fluoride intake from one brushing per day would result in ingestion of 18, 13, and 9 $\mu g \cdot kg^{-1} \cdot d^{-1}$, respectively. It is evident that toothbrushing substantially increases the fluoride exposure, particularly for 2- to 3-year-old children and, of course, for children who brush twice daily.

Surprisingly few reports concern the relationship between use of fluoridated dentifrices and dental fluorosis. Although more than 90 percent of children who brush their teeth use fluoridated dentifrices, one might anticipate that other variables might make it difficult to document a relationship between the frequency of toothbrushing and the occurrence of dental fluorosis. Such variables include the quantity of dentifrice applied to the toothbrush, how much dentifrice is swallowed (e.g., whether a child rinses the mouth after toothbrushing), and the relation of toothbrushing to meals (70,71). It has been demonstrated that fluoride absorption (bioavailability) is low when toothbrushing occurs shortly after a meal (72). Nevertheless, an association between the frequency of toothbrushing by young children and subsequent dental fluorosis of the permanent teeth has been demonstrated (24,25).

*Fluoride Supplements.* In 1989 use of fluoride supplements was reported to be 15 percent for those younger than 2 years of age, 16 percent for those 2–4 years of age and 8 percent for those 5–17 years of age (55). In view of the fluoride intake from soft drinks and fruit juices and from fluoridated dentifrices, it seems likely that total fluoride intake greater than 70 $\mu g \cdot kg^{-1} \cdot d^{-1}$ will be achieved by many young children living in communities with nonfluoridated water if they are consuming the recommended dose of a fluoride supplement.

**Changes in Children's Intake of Fluoride.** Because drinking water was for many years the major dietary source of fluoride for children, fluoride exposure of children was quite low until the late 1940s. Since then, the percent of individuals consuming fluoridated water has steadily increased. The increase in percentage of communities with fluoridated water has resulted in an increase in the mean content of fluoride not only in soft drinks and fruit juices, but in canned goods (notably soups), leading to increased intake of fluoride by individuals in communities with nonfluoridated water. With the introduction of fluoridated dentifrices in the late 1950s, children were exposed to an additional source of fluoride, and this exposure increased as the percentage of dentifrices containing fluoride increased. By 1980 nearly all dentifrices marketed in industrialized countries were fluoridated (66), and there is no reason to believe that children's intake of fluoride from dentifrices is greater now than in the 1980s. Because the recommended dosage of fluoride supplements has decreased progressively since 1972 (47-50), it is likely that consumption of fluoride supplements contributes less to dental fluorosis at present than in the past. On the other hand, even a relatively modest intake of fluoride from a supplement, if imposed on a substantial intake from other sources (beverages and dentifrices), may raise the total fluoride intake to an undesirable level.

In summary, for children younger than 7 years of age, as for infants, fluoride intake has shown a progressive increase; thus, one may anticipate that the prevalence of dental fluorosis in permanent teeth will be found to be greater in children born in the 1990s than in those born in the 1970s or 1980s.

## Recommendations

Our goal should be to maximize the effect of fluoride in decreasing the prevalence of dental caries, while controlling the total intake of fluoride so as to decrease the risk of fluorosis. In the absence of evidence of major benefit from fluoride consumption during infancy, it seems desirable to limit intakes of fluoride to amounts less than those estimated to be associated with increased risk of enamel fluorosis. Until more data are available on the relation between fluoride intake at various ages and enamel fluorosis, we suggest striving for intakes less than 70 $\mu g \cdot kg^{-1} \cdot d^{-1}$. To avoid greater intakes, we recommend use of water with relatively low fluoride content (e.g., 0 to 0.3 mg/L) as a diluent for infant formulas and recommend that no fluoride supplements be given to infants.

For children from 1 to 7 years of age, our goal should be to provide the repeated addition of small amounts of fluoride to the oral fluids. Consumption of fluoridated water is therefore highly recommended. The regular use of fluoridated dentifrices is also an effective means of decreasing the prevalence of dental caries. However, with the knowledge that small children swallow much of the applied dentifrice, there is an urgent need for education of the general population to the need for adult supervision of toothbrushing of small children, including the limitation in amount of dentifrice applied to the brush. We suggest that the amount be no more than 0.25 g per brushing. With widespread public awareness of the relationship between fluoride intake from dentifrices and development of dental fluorosis, manufacturers might be motivated to promote the use by small children of fluoridated dentifrices with lower fluoride concentrations. Because we now believe that the primary role of fluoride in caries prevention is through a local action at the tooth surface rather than through a preeruptive change in the enamel composition, there is unlikely to be a major benefit from consumption of fluoride tablets, especially tablets that are immediately swallowed rather than sucked or chewed before swallowing. In our opinion, the risk of dental fluorosis will generally outweigh the benefit derived from caries prevention when fluoride supplements are given to children younger than 5 years of age. Therefore, supplements should be recommended for these children only after it has been established that fluoride intake from all sources is less than 0.25 mg/d.

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