Fluoride Intake by Infants

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Abstract

Many infants are fully or partially breast fed during the early months of life; however, the percentage of such infants decreases to about 30 percent by 4 months of age. The majority of US infants are fed formulas for most of the first 10 months of life. Although fluoride (F) intakes by fully breast-fed infants are low, F intakes by partially breast-fed infants and by formula-fed infants are highly variable, depending primarily on the F content of the water used to dilute concentrated liquid or powdered infant formula products. In communities with F content of the drinking water less than 0.3 ppm, F consumption by many infants will be 30 to 40 $\mu g \cdot kg^{-1} \cdot d^{-1}$. The addition of a F supplement of 0.25 mg/d for a 4 kg infant would increase the F intake by 63 $\mu g \cdot kg^{-1} \cdot d^{-1}$, resulting in a total intake of about 100 $\mu g \cdot kg^{-1} \cdot d^{-1}$, an intake in the range believed to be associated with development of fluorosis of the permanent teeth. However, for the US infant population generally, many fewer infants are exposed to high F intakes from formula plus a supplement (recommended only for communities with water providing less than 0.3 ppm F) than from formula alone in communities with F content of 1 ppm in the drinking water. In assessing the possible effects of F intake during infancy on development of fluorosis, it is important to recognize that infant feeding practices have changed greatly during the past 30 years. In the 1960s, most infants over 4 months of age were fed fresh cow's milk and intakes of F were therefore low. By the mid 1970s a trend toward more extended feeding of formula was evident and this trend has continued into the 1990s. Prolonged exposure to high intakes of fluoride during infancy is much more common now than in the past. [J Public Health Dent 1999;59(4):229-34].

Key Words: infant feeding, fluorosis, fluoride supplements, fluoride intake.

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 (1-3). Although the extent of benefits achieved from fluoride consumption during infancy is uncertain, there is no question that such consumption may be an overriding factor in development of enamel fluorosis of the permanent teeth. A study of 12- and 13-year-old children who had lived since birth in a Swedish city with a fluoride concentration of 1.2 mg/L in the drinking water 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 (4). Similarly, in the United States, Walton and Messer (5) 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.

Because so much of the infant's diet consists of milk or formula, and because fluoride concentrations are low in human milk and cow's milk but may be quite high in infant formulas, fluoride intakes by infants vary widely. Moreover, major changes in infant feeding practices have occurred over the past 30 years and knowledge of current feeding practices is therefore of limited usefulness in evaluating reports concerning individuals who were infants 15 or 30 years ago. We shall review trends in infant feeding over the past 30 years and relate these to fluoride intakes by infants. We shall conclude by offering an opinion on the desirability of administering fluoride supplements to infants, an opinion based in part on estimates of total intakes of fluoride by supplemented infants.

Fluoride Concentrations of Infant Foods

Human Milk and Cow's Milk. Fluoride is poorly transported from plasma to milk (6-8), and concentrations of fluoride in milk remain low even when intakes of fluoride by the woman (or other mammal) are high (9). Concentrations of fluoride generally range from 5 to 10 μg/L in human milk (7,9-11) and from 30 to 60 μg/L in cow's milk (Ekstrand, unpublished data) as it reaches the retail market (Table 1).

Infant Formulas. Infant formulas are commercially prepared as ready-to-feed (667 kcal/L), as concentrated liquids (1,333 kcal/L), or as powders. Their fluoride concentrations are summarized in Table 1 (12,13). Fluoride concentrations of ready-to-feed formulas are relatively low, generally 100–300 μg/L. 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). Depending primarily on the fluoride content of the water used for diluting the concentrated liquid formulas, fluoride content of the formulas as fed commonly ranges from 200 to 620 μg/L (10,14) (Table 2).

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Mean fluoride concentration of powdered formulas before dilution with water is about 690 μg/kg for milk-based products (Table 1) and somewhat higher for isolated soy protein-based formulas. In reconstituting powdered formulas, 145 g of powder are diluted with 880 ml of water to make 1 L of 667 kcal/L formula. Fluoride content of powdered formulas as fed varies widely depending primarily on the fluoride content of the water used for dilution, and is generally 276 to 980 μg/L (Table 2).

The fluoride concentration of infant formulas in the United States was not always as well defined as is indicated in Table 1. Until 1978, formulas marketed as liquids were commercially prepared with the local water supply. 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 was generally about 1,000 μg/L, and the fluoride concentration of a concentrated liquid isolated soy protein-based formula was generally about 800 mg/L, whereas the fluoride content of the same formulas made in plants with low fluoride content of the water were similar to the values listed in Table 1 (14). 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 in-

TABLE 1
Fluoride Concentrations of Infant Foods
[Modified from Fomon and Ekstrand (Ref. 10)]

Food	F Concentration* (μg/L)
Human milk†	5–10
Cow's milk†	30–60
Formula‡	
Ready to feed	100–300
Concentrated liquid	
Milk-based	100–300
Isolated soy protein-based	100–400
Powdered	
Milk-based	400–1,000
Isolated soy protein-based	1,000–1,600
Beikost¶	
Products other than dry cereals, wet-pack cereal-fruit products, fruit juices and poultry-containing products	100–300
Fruit juices	
Produced with nonfluoridated water	10–200
Produced with fluoridated water	100–1,700
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
Poultry-containing products	100–5,000

*Concentration ranges have been rounded off; most reported values fall within the ranges listed in the table.
†Human milk from Esala et al. (11), Spak et al. (9), Ekstrand et al. (7); cow's milk from Ekstrand (unpublished).
‡Formulas from Johnson and Bawden (12) and McKnight-Hanes et al. (13).
¶Beikost from Singer and Ophaug (15) and Dabeka et al. (16).

TABLE 2
Estimated Fluoride Intakes from Milks and Formulas [Modified from Fomon and Ekstrand (10)]

Milk or Formula	F Concentration (μg/L)			F Intake* ($\mu g \cdot kg^{-1} \cdot d^{-1}$)		
	Formula	Water	As Fed	Formula Intake 170 $ml \cdot kg^{-1} \cdot d^{-1}$	Formula Intake 150 $ml \cdot kg^{-1} \cdot d^{-1}$	Formula Intake 120 $ml \cdot kg^{-1} \cdot d^{-1}$
Human milk			6	1	1	1
Cow's milk			40	6	6	5
Formulas		—	200	34	30	24
Ready-to-feed milk-based	200					
Conc. liquid milk-based	200	200	200	34	30	24
	200	1,000	600	102	90	72
Isolated soy protein-based	240	200	270	46	41	22
	240	1,000	620	105	93	74
Powdered milk-based	690†	200	276‡	47	41	33
	690	600	700	119	105	84
	690	1,000	980	167	147	118

*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 [Fomon and Bell (14)]. An exclusively formula-fed infant consuming a 667 kcal/L formula will therefore consume approximately 170 $ml \cdot kg^{-1} \cdot d^{-1}$ from birth to 2 months of age and approximately 150 $ml \cdot kg^{-1} \cdot d^{-1}$ from 2 to 4 months of age. 120 $ml \cdot kg^{-1} \cdot d^{-1}$ is an estimate of formula intake by older infants.
†μg/kg of formula powder.
‡Assumes that 145 g of fomula diluted with 880 ml of water make 1 liter.

fant formula.

Beikost. Beikost is a collective term for foods other than milk or formula fed to infants. The fluoride concentration of most beikost items is quite modest (15,16). The exceptions are some dry infant cereals, fruit juices, and poultry products (Table 1); nevertheless, as will be discussed, even these foods do not often contribute importantly to total fluoride intake. Dry infant 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 quite high (Table 1). When fruit juices are prepared from concentrates, appreciable amounts of water are added and the fluoride concentration is influenced by the fluoride content of the local water supply. Strained poultry is prepared from mechanically deboned chicken or turkey and the fluoride present in comminuted bone contributes to the fluoride content of the product.

Fluoride Intakes

Fluoride intakes by infants are best discussed in the context of estimates of intakes required to produce adverse effects on the permanent teeth. These adverse effects consist of enamel fluorosis, which may be cosmetically objectionable, but—except in its most severe form—is of no other medical or dental significance. Various investigators (4,17,18) estimated that intakes of fluoride from 40–100 $\mu g \cdot kg^{-1} \cdot d^{-1}$ are associated with development of enamel fluorosis of the permanent teeth. Although we must rely on these estimates until better ones are available, confidence in them is limited because they (1) are based on few data, (2) fail to distinguish between doses of fluoride resulting in high peak plasma fluoride concentrations (as occur with consumption of a supplement) and lower and more sustained plasma concentrations (as occur 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.

Young infants whose entire energy intake is provided by milk or formula during the first two months of life commonly consume ca. 170 $ml \cdot kg^{-1} \cdot d^{-1}$ and about 150 $ml \cdot kg^{-1} \cdot d^{-1}$ from 2 to 4 months of age, where consumption of milk or formula by older infants who obtain a portion of energy intake from beikost may be about 120 $ml \cdot kg^{-1} \cdot d^{-1}$. Table 2 shows results of calculations of fluoride intakes by infants who consume 150 or 120 $ml \cdot kg^{-1} \cdot d^{-1}$ of various milks or formulas.

Human Milk. Intake of fluoride by an exclusively breast-fed infant consuming 170 $ml \cdot kg^{-1} \cdot d^{-1}$ is generally less than 2 $\mu g \cdot kg^{-1} \cdot d^{-1}$ (Table 2). However, many breast-fed infants are given at least one formula feeding daily, and this feeding often is made from a powdered product. As may be calculated from the values presented in Table 2, a feeding of 150 ml of powdered formula (as might be consumed by a 1-month-old infant) will provide 41 to 147 μg of fluoride—10 to 37 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for a 4 kg infant; similarly, a feeding of 180 ml of powdered formula (as might be consumed by a 3-month-old infant) will provide 50 to 176 μg of fluoride—8 to 29 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for a 6 kg infant.

Infant Formulas. Intakes of fluoride by formula-fed infants are greater than those by breast-fed infants or infants fed cow's milk— with some formulas, many times greater. In the calculations presented in Table 2 for infants consuming 170 $ml \cdot kg^{-1} \cdot d^{-1}$ of formula diluted with water providing 1 mg of fluoride per liter, fluoride intake is 102 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for an infant consuming a concentrated liquid milk-based formula, 105 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for an infant consuming a concentrated liquid isolated soy protein-based formula, and 167 $\mu g \cdot kg^{-1} \cdot d^{-1}$ for an infant consuming a powdered milk-based formula. For older infants with formula intake of 120 $ml \cdot kg^{-1} \cdot d^{-1}$, corresponding intakes of fluoride from formula diluted with water providing 1 mg of fluoride per liter are 72, 89, and 118 $\mu g \cdot kg^{-1} \cdot d^{-1}$. Infants consuming 120 $ml \cdot kg^{-1} \cdot d^{-1}$ generally obtain additional, usually small, quantities of fluoride from beikost.

Cow's Milk. Intakes of fluoride by an infant consuming 120 $ml \cdot kg^{-1} \cdot d^{-1}$ of fresh cow's milk are ca. 5 $\mu g \cdot kg^{-1} \cdot d^{-1}$.

Beikost. The first foods other than milk or formula commonly fed to infants are dry cereals diluted with milk or formula. However, the quantity of dry cereal consumed at a feeding is quite small (about 10 g of powdered cereal in a 70 g serving—i.e., the quantity that might be consumed by a 5-month-old infant). Consumption of 10 g of a cereal providing 5 ppm fluoride results in an intake of 50 μg of fluoride (10 μg/kg for a 5 kg infant). Although fruit juices vary widely in fluoride concentration, most do not contain large amounts of fluoride and probably contribute relatively little to total fluoride intake. The fluoride concentration of strained chicken and turkey is generally high, sometimes as high as 5 ppm (Table 1); however, few infants consume these products regularly. It seems likely that the fluoride intake from beikost rarely averages more than 20 $\mu g \cdot kg^{-1} \cdot d^{-1}$.

Supplements. A fluoride supplement of 0.25 mg/d contributes 63 $\mu g \cdot kg^{-1} \cdot d^{-1}$ to the intake of a 4 kg infant and 28 $\mu g \cdot kg^{-1} \cdot d^{-1}$ to the intake of a 9 kg infant.

Fluoride Bioavailability and Retention from Infant Foods and from a Fluoride Supplement

Development of dental fluorosis is probably more closely related to retention of fluoride than to fluoride intake. Development of dental fluorosis also may be related to occurrence of high plasma concentrations even if such peak plasma fluoride values are not sustained. In a recent series of studies of infants, we determined intake, absorption (bioavailability), excretion, and retention of fluoride under steady-state conditions (19). Infants (mean body weight=9.3 kg) consuming low intakes of fluoride (approximately 20 $\mu g \cdot kg^{-1} \cdot d^{-1}$) from infant formula and beikost were studied with and without administration of a fluoride supplement (0.25 mg). Fluoride absorption from the infant formula and beikost was high, generally more than 90 percent of intake, as has been reported previously for absorption of fluoride from human milk and infant formula (7). When no fluoride supplement was given, fluoride retention was low (mean=12.5% of intake) and some infants were in negative fluoride balance. In contrast, when the fluoride supplement was given, a high percentage of the dose was retained. There was little difference in retention whether the dose was given with a feeding (68.1% retained) or between feedings (73.0% retained). Thus, feeding of infant formula failed to demonstrate in infants the major inhibitory effect of food on fluoride absorption

that has been demonstrated in adult subjects when milk or a calcium-rich breakfast was given with the supplement (20,21).

In pharmacokinetic studies with infants, we have demonstrated that fluoride retention from a fluoride supplement is high for younger as well as for older infants (22). Fluoride retention as a percentage of absorbed fluoride was greater in our studies of infants than in similar studies of adults (23), probably because of a greater capacity of the infant to deposit fluoride in hard tissues. After administration of a dose of 0.25 mg of fluoride, mean peak plasma fluoride concentration was 63 μg/L (SD=11 μg/L). The daily peak plasma fluoride concentration associated with increased risk of dental fluorosis in human subjects is unknown.

Changing Patterns of Fluoride Intake over the Past 30 Years

The remarkable changes in infant feeding practices that have occurred in the United States over the past 30 years are illustrated in Figures 1–3 (24). In 1971 only about 25 percent of infants were breast fed during the early weeks of life and fewer than 10 percent of infants were breast fed for as long as 4 months. After 1971 the percentage of infants who were breast fed increased each year until 1984, when nearly 60 percent of infants were breast fed during the first few weeks of life and more than 25 percent of infants were breast fed for at least 6 months (Figure 1). Concurrently with the increase in breast feeding since 1971 was a change in the age of introduction of fresh cow's milk. In 1971 about one-third of infants were fed fresh cow's milk by 4 months of age and nearly 80 percent were fed fresh cow's milk by 6 months of age (Figure 2). By 1980 fewer than 20 percent of infants were fed fresh cow's milk by 6 months of age, and by 1991 fewer than 10 percent of infants were fed fresh cow's milk by 6 months of age.

Trends in feeding infant formulas are predictable from the data in Figures 1 and 2. In 1971, when relatively few infants were breast fed during the early weeks of life, most infants were formula fed; however, with the early introduction of fresh cow's milk, the percentage of formula-fed infants rapidly declined (Figure 3). In 1991, when a much higher percentage of infants

FIGURE 1
Percentage of Infants of Various Ages Breast Fed in the United States in 1971, 1984, and 1991. [From Fomon (24); data of Martinez and Nalezienski (25) for 1971; data of Martinez and Krieger (26) for 1984; data for 1988 based on personal communication from Greenbaum S. Ross Laboratories, Columbus, OH, 1992. The percentages of infants who were breast fed (Figure 1) and formula fed (Figure 3) add up to more than 100% because some breast-fed infants also were fed formulas.]

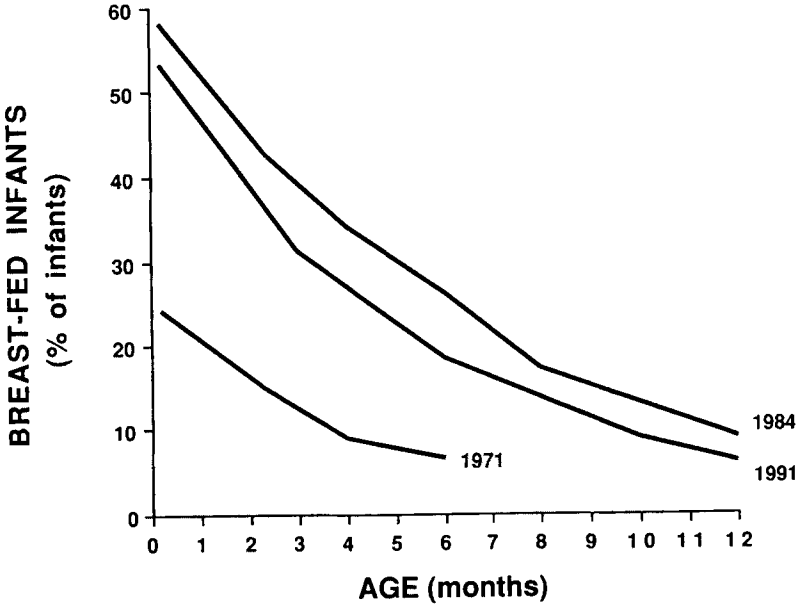

FIGURE 2
Percentage of Infants of Various Ages Fed Fresh Cow's Milk in the United States in 1971, 1980, and 1991. [From Fomon (24); data for 1971 and 1980 from Martinez et al. (27); data for 1991 based on personal communication from Greenbaum S. Ross Laboratories, Columbus, OH, 1992.]

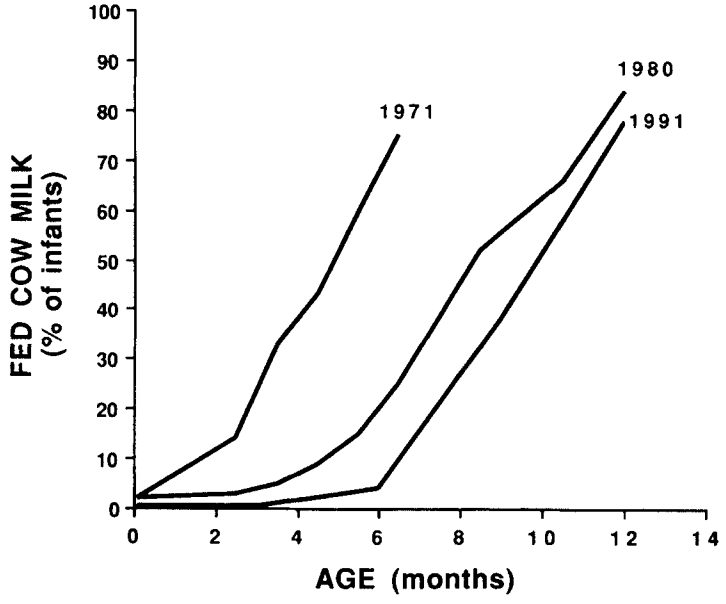

FIGURE 3
Percentage of Infants of Various Ages Fed Commercially Prepared Formulas in the United States in 1971, 1980, and 1991. [From Fomon (24); data of Martinez et al. (27) for 1971 and 1980; data for 1991 based on personal communication from Greenbaum S. Ross Laboratories, Columbus, OH, 1992. The percentages of infants who were breast fed (Figure 1) and formula fed (Figure 3) add up to more than 100% because some breast-fed infants also were fed formulas.]

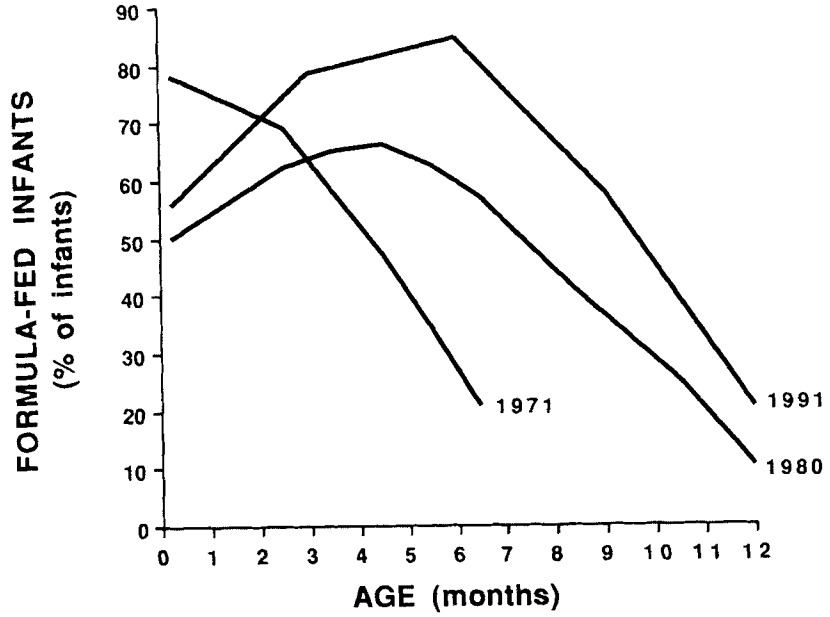

TABLE 3
Comparison of Fluoride Intakes from Milks and Formula During the 1960s and Early 1970s with Those During the 1980s and Early 1990s

	1960s and Early 1970s		1980s and Early 1990s	
Age Interval, Feeding	F Intake* $\mu g \cdot kg^{-1} \cdot d^{-1}$	Estimated % of Infants	F Intake* $\mu g \cdot kg^{-1} \cdot d^{-1}$	Estimated % of Infants
Birth to 1 month				
Human milk	1–37	20	1–37	50–60
Infant formula	34–167	80	34–167	40–50
Cow's milk	—	—	—	—
1 to 4 months				
Human milk	1–29	<10	1–29	35–40
Infant formula	30–147	>70	30–147	60–65
Cow's milk	6	20	—	—
4 to 10 months				
Human milk	—	—	137	15
Infant formula	24–118	<20	24–118	55
Cow's milk	5	>80	5	30

*Fluoride intakes by exclusively breast-fed infants do not exceed 1 $\mu g \cdot kg^{-1} \cdot d^{-1}$; however, many breast-fed infants also receive infant formula and the range of intakes in the table include those of partially breast-bed infants. Estimates of fluoride intake from infant formulas have been calculated from values in Table 2 and are therefore somewhat less than would be the case if calculations had been based on concentrations of fluoride in concentrated liquid and powdered infant formulas actually marketed in the 1960s and early 1970s.

were breast fed during the early weeks of life, fewer infants were formula fed; but, as infants were weaned from the breast, they were fed formulas. Thus, in 1991 more than 80 percent of 6-month-old infants were fed formulas; even at 9 months of age, most infants were fed infant formulas rather than cow's milk. The changes in infant feeding practices over the past 30 years have been associated with major changes in the pattern of fluoride intake.

Comparison of Fluoride Intakes by Infants in the 1960s and Early 1970s with Those in the 1980s and Early 1990s

The changes in fluoride intakes from the 1960s to the 1990s may be considered for three age intervals: birth to 1 month, 1 to 4 months, and 4 to 10 months (Table 3). After 10 months of age, most infants were fed fresh cow's milk in the 1960s and this continued to be the practice even in the early 1990s.

In interpreting the estimates of fluoride intake from infant formulas presented in Table 3, it should be noted that intakes were calculated on the basis of concentrations listed in Table 1. These concentrations are somewhat less, especially for concentrated liquid formulas, than those of formulas commonly consumed in the 1960s and early 1970s.

Birth to 1 Month of Age. In the 1960s and early 1970s, most infants were fed infant formulas during the first month of life and fluoride intakes, although variable, were often high. By contrast, in the 1980s and early 1990s, many infants were fully or partially breast fed and their intakes of fluoride therefore were considerably less than those characteristic of the 1960s and early 1970s.

One to 4 Months of Age. From 1 to 4 months of age, a greater percentage of infants were fed infant formulas in the 1960s and early 1970s than in the 1980s and early 1990s. For infants in this age interval, intakes of fluoride were therefore greater in the 1960s and early 1970s. In the 1980s and early 1990s, many infants were fully or partially breast fed and their intakes of fluoride were therefore considerably fewer than those characteristic of the 1960s and early 1970s.

Four to 10 Months of Age. The greatest change in fluoride intake from the 1960s to the present applies to the age interval from 4 to 10 months of age. In the 1960s and early 1970s, a high percentage of infants were fed fresh cow's milk and fluoride intakes by these infants were quite low. As indicated in Table 3, in this age interval an estimated 55 percent of infants were fed infant formulas in the 1980s and early 1990s and less than 20 percent of infants were fed infant formulas in the 1960s and early 1970s.

In summary, fluoride intakes at present are less during the first 4 months of life and greater from 4 to 10 months of age than was the case in the 1960s and early 1970s. Although fluoride intakes during the first 4 months of life now generally are less than they were 20 years ago, more than 50 percent of infants are currently formula fed by 1 month of age, and these infants are likely to be continuously exposed to high intakes of fluoride for 9 or 10 months—a circumstance quite rare in the 1960s and early 1970s.

The minority of infants given a daily fluoride supplement (0.5 mg/d) in the 1960s and early 1970s received quite high intakes of fluoride; however, because fluoride supplements were recommended only for infants living in communities with fluoride concentration of the water supply less than 0.3 mg/L and because adherence to the recommendation even for these infants was unlikely to be high, the number of infants so exposed was probably not great.

Recommendations Regarding Fluoride Intakes for Infants

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. At the least, we should avoid intakes of 100 $\mu g \cdot kg^{-1} \cdot d^{-1}$—the upper limit of the range of estimates believed to be associated with increased risk of enamel fluorosis. To limit fluoride intake to amounts <100 $\mu g \cdot kg^{-1} \cdot d^{-1}$, it is necessary to avoid use of fluoridated water (1 mg of fluoride per liter) as a diluent for powdered infant formulas (except when such formulas are used as a supplement for breast-fed infants) and as a diluent for concentrated liquid formulas that are to be fed to infants younger than 2 months of age.

If, in the future, fluoride supplements are recommended for infants, they will presumably be recommended for those living in communities in which the drinking water provides less than 0.3 mg of fluoride per liter. A 4 kg formula-fed infant living in such a community and fed 170 $ml \cdot kg^{-1} \cdot d^{-1}$ of powdered formula might obtain 47 $\mu g \cdot kg^{-1} \cdot d^{-1}$ of fluoride (Table 2) and 63 $\mu g \cdot kg^{-1} \cdot d^{-1}$ from a fluoride supplement of 0.25 mg for a total fluoride intake of 110 $\mu g \cdot kg^{-1} \cdot d^{-1}$. Even if the dosage of fluoride supplement were decreased to 0.125 mg, total fluoride intake would be 78 $\mu g \cdot kg^{-1} \cdot d^{-1}$. Until more is known about the efficacy and safety of fluoride consumption by infants, it seems preferable to avoid administration of fluoride supplements during the first year of life.

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