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The American Academy of Pediatric Dentistry
Volume 9 Number 1

The fluoride content of infant formulas available in 1985

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Abstract

The purpose of this study was to measure the fluoride content of several brands of commercially available infant formulas obtained from various geographic locations in the United States. Fluoride determinations were accomplished using a modification of the Taves microdiffusion method.

Ready-to-feed infant formulas were found to contain significantly more fluoride as a group than either the concentrate or powder types of infant formulas ($P < 0.001$). No significant differences in fluoride concentrations were found between the concentrate and powder types of infant formulas. Soy-based infant formulas were found to contain more fluoride than the milk-based formulas for all groups tested. These differences were statistically significant for the concentrate and powder types of infant formulas ($P < 0.001$). It appears that fluoride concentrations in infant formulas now are controlled at lower levels than has been reported in the past.

In the past, some infant formulas have been shown to contain relatively high levels of fluoride.[1] The fluoride content was noted to vary between products and for the same product purchased in different cities. This variability was explained by differences in the fluoride content of water used in processing them.

Because of the relatively high fluoride concentrations found in some infant formulas, these studies suggested that infants who consumed such products living in areas with nonfluoridated water would run the risk of fluorosis if given a fluoride supplement. It was recommended that children drinking infant formulas and residing in nonfluoridated areas not be given a fluoride supplement during the first 6 months of life.[1]

More recently, reports in the literature have indicated that manufacturers of infant formulas have agreed to reduce the fluoride content of the water used in processing their products to < 0.15 ppm F.[2] Adequate documentation of such reduction does not exist in the literature. The purpose of this study was to determine the fluoride content of commercially available infant formulas obtained from various geographic locations in the United States.

Methods and Materials

Infant formulas tested in this project were purchased from local supermarkets in 7 cities across the United States: Minneapolis, Minnesota; Los Angeles, California; New York, New York; Largo, Florida; Dallas, Texas; Seattle, Washington; and Chapel Hill, North Carolina. A sample of all infant formulas reasonably available to the purchaser in each city was gathered for testing. Between 7 and 24 products were collected from each location.

Concentrated or powdered infant formulas were reconstituted with deionized water according to the manufacturer's recommendations before fluoride determinations were made. Assay of the deionized water consistently give a fluoride content of < 0.01 ppm F. Additionally, the samples collected in Chapel Hill were reconstituted with optimally fluoridated tap water (1.1 ppm) to determine if all of the fluoride added from the tap water could be recovered from the formulas. Ready-to-feed formulas were tested without dilution.

Triplicate 1-ml (1 g) samples of each product were assayed using the microdiffusion method described by Taves as modified by Whitford and Reynolds.[3] An Orion solid-state fluoride electrode coupled with a Corning microsample calomel reference electrode was used to assay the diffused samples. Measurement error was ± 2.58%.

Intergroup means were compared statistically using the *t*-test with $P < 0.05$ regarded as significant.

[1] Wiatrowski et al. 1959; Adair and Wei 1978; Tinanoff and Mueller 1978; Singer and Ophaug 1979.

[2] Tinanoff et al. 1981; Feigal 1983.

[3] Taves 1968; Whitford and Reynolds 1979.

TABLE 1. Mean Fluoride Concentrations (ppm F) of Ready-to-Feed Type Infant Formulas

	Chapel Hill, NC	*Largo, FL*	*New York, NY*	*Minneapolis, MN*	*Dallas, TX*	*Los Angeles, CA*	*Seattle, WA*
Advance	0.21 ± 0.002	0.28 ± 0.001				0.18 ± 0.003	
Enfamil	0.11 ± 0.000	0.32 ± 0.007			0.34 ± 0.009	0.12 ± 0.002	0.16 ± 0.006
Enfamil + Fe	0.17 ± 0.005	0.22 ± 0.005			0.07 ± 0.001	0.21 ± 0.009	0.05 ± 0.001
Isomil	0.30 ± 0.007	0.20 ± 0.003	0.34 ± 0.008	0.15 ± 0.008	0.28 ± 0.005	0.22 ± 0.007	
Isomil SF		0.10 ± 0.003					
Nursoy							0.15 ± 0.008
Pedialyte		0.19 ± 0.001	0.07 ± 0.003			0.06 ± 0.001	
Prosobee	0.30 ± 0.011	0.21 ± 0.006	0.32 ± 0.013	0.33 ± 0.017	0.28 ± 0.003	0.22 ± 0.009	0.20 ± 0.008
Similac	0.19 ± 0.002	0.38 ± 0.012		0.06 ± 0.003	0.21 ± 0.005		
Similac + Fe	0.17 ± 0.005	0.12 ± 0.002			0.22 ± 0.005	0.21 ± 0.016	0.13 ± 0.003
Similac + whey + Fe		0.11 ± 0.001					
SMA + Fe	0.23 ± 0.004	0.23 ± 0.001		0.24 ± 0.006	0.23 ± 0.002	0.26 ± 0.003	0.19 ± 0.005
SMA + 1o Fe		0.24 ± 0.003					
i-Soyalac		0.37 ± 0.005					
Soyalac		0.19 ± 0.007				0.23 ± 0.005	

± (standard deviation of triplicate assays).

Results

The mean ppm fluoride values for the triplicate assays for each sample are listed in Tables 1–3. Variations in fluoride content were found among samples of the same product collected in different locations. This variation was most noticeable in the ready-to-feed group. Four products (Enfamil, Enfamil with Iron, Isomil, and Similac) showed the most variation (up to 0.32 ppm F for the same product purchased in different locations). A sample of Similac purchased in Largo, Florida, was found to have the highest fluoride content of all the formulas tested (0.38 ppm F).

As seen in Table 4, the ready-to-feed formulas as a group contained significantly ($P < 0.001$) more fluoride than the concentrate or powder-type formulas. The mean values for the concentrated and powdered products were not significantly different.

Table 5 lists the fluoride concentrations of the 3 groups of infant formulas categorized into milk-based and soy-based products. The fluoride content of the soy-based formulas was found to be greater than that of the milk-based formulas in all 3 groups, but the differences were statistically significant only in the concentrated and powdered formulas.

Table 2 lists the values for the concentrated infant formulas from Chapel Hill that were diluted with deionized water (first column), and with water containing 1.1 ppm F (second column). Table 3 lists the same information for the powdered infant formulas. The recovery of fluoride added in the fluoridated water

TABLE 2. Mean Fluoride Concentrations (ppm F) of Concentrate-Type Infant Formulas

	Chapel Hill, NC		*Largo, FL*	*New York, NY*	*Minneapolis, MN*	*Dallas, TX*	*Los Angeles, CA*	*Seattle, WA*
Advance	0.0757 ± 0.0010	*0.64 ± 0.021						0.04 ± 0.001
Enfamil	0.0803 ± 0.0010	0.65 ± 0.018		0.06 ± 0.001	0.08 ± 0.002	0.04 ± 0.002	0.04 ± 0.002	0.10 ± 0.002
Enfamil + Fe	0.0637 ± 0.0010	0.62 ± 0.009		0.07 ± 0.002		0.10 ± 0.003		0.03 ± 0.001
Isomil	0.320 ± 0.0020				0.14 ± 0.005	0.16 ± 0.005	0.18 ± 0.009	0.19 ± 0.000
i-Soyalac							0.34 ± 0.011	0.17 ± 0.003
Nursoy	0.0700 ± 0.0020		0.15 ± 0.004			0.15 ± 0.006		0.08 ± 0.003
Prosobee	0.0637 ± 0.0010	0.72 ± 0.006				0.19 ± 0.009	0.18 ± 0.001	0.16 ± 0.004
Similac	0.170 ± 0.0020			0.06 ± 0.002		0.11 ± 0.004		0.05 ± 0.001
Similac + Fe	0.0746 ± 0.0010			0.06 ± 0.002	0.03 ± 0.001	0.14 ± 0.044	0.06 ± 0.003	0.04 ± 0.001
SMA + whey + Fe	0.0480 ± 0.0020	0.60 ± 0.009	0.04 ± 0.001		0.04 ± 0.002	0.05 ± 0.002		
SMA	0.0847 ± 0.0010	0.65 ± 0.023				0.08 ± 0.002		
SMA + Fe					0.09 ± 0.005		0.09 ± 0.001	0.07 ± 0.003
SMA + 1o Fe								0.11 ± 0.001
Soyalac						0.13 ± 0.005		0.05 ± 0.002

All formulas (except those in column with *) were diluted with 1:1 deionized water. * Formulas in this column were diluted 1:1 with water containing 1.1 ppm F^-. ± (standard deviation of triplicate assays).

TABLE 3. Mean Fluoride Concentrations (ppm F) of Powder-Type Infant Formulas

	Chapel Hill, NC		*Largo, FL*	*Minneapolis, MN*	*Dallas, TX*	*Los Angeles, CA*	*Seattle, WA*
Enfamil	0.15 ± 0.005	*1.14 ± 0.050	0.12 ± 0.003		0.12 ± 0.006		
Enfamil + Fe	0.15 ± 0.003	1.19 ± 0.030	0.11 ± 0.002			0.14 ± 0.006	
Isomil	0.24 ± 0.009	1.25 ± 0.022	0.19 ± 0.001		0.20 ± 0.003	0.18 ± 0.002	0.18 ± 0.003
Prosobee	0.18 ± 0.000	1.22 ± 0.030	0.24 ± 0.006			0.20 ± 0.006	0.23 ± 0.002
Similac			0.03 ± 0.002	0.06 ± 0.000	0.04 ± 0.002	0.04 ± 0.001	0.04 ± 0.001
Similac + Fe	0.03 ± 0.000	1.00 ± 0.048		0.04 ± 0.001	0.04 ± 0.001		0.09 ± 0.000
SMA + whey + Fe			0.15 ± 0.005				
SMA + Fe					0.06 ± 0.002		0.07 ± 0.000
SMA + 1o Fe							0.05 ± 0.003
SMA			0.05 ± 0.001				

All formulas (except those in column with *) were diluted with 1:1 deionized water. * Formulas in this column were diluted 1:1 with water containing 1.1 ppm F^-. ± (standard deviation of triplicate assays).

was 92–100%. Because the fluoride content for any product could be estimated accurately if the fluoride content of the water were known, it seemed unnecessary to repeat such determinations for the products from other locations.

Discussion

Several studies were reported on the fluoride content of infant formulas during the period 1975–79. Wiatrowski et al. (1959) found that concentrated milk formulas contained up to 0.51 ppm F when diluted with distilled tap water. Tinanoff and Mueller (1978) tested formulas purchased in the mideastern and eastern United States. The fluoride content of ready-to-feed products ranged up to 0.86 ppm, and some concentrates nearly 0.40 ppm prior to dilution. Adair and Wei (1978) reported that ready-to-feed formulas purchased in Iowa City, Iowa, contained up to 0.78 ppm fluoride. Milk-based concentrates and powders diluted with deionized water contained up to 0.38 ppm, while soy-based, ready-to-feed products contained as high as 0.92 ppm and the concentrates contained a maximum of 0.47 ppm fluoride. Singer and Ophaug (1979) found ready-to-feed formulas containing as high as 0.76 ppm and concentrates as high as 0.58 ppm fluoride.

The relatively high concentrations of fluoride in a substantial number of the formulas tested by these investigators resulted in recommendations that children drinking formulas not be supplemented with fluoride during the first 6 months of life, even when the water supply was nonfluoridated. Confusion on this point has persisted, especially when it was reported that formula manufacturers had agreed to control the fluoride content of the water used in processing to < 0.15 ppm.[4] At that fluoride content in the water, milk-based formula products should contain no more than 0.10 ppm F as ready-to-feed or as concentrates or powders diluted with nonfluoridated water. However, no systematic assay of formula products collected from various locations had been conducted.

In the study reported here 140 samples of 39 products collected from 7 locations in the United States were assayed in triplicate for fluoride content. The highest observed value for all ready-to-feed products, or concentrated or powdered formulas mixed with deionized water was 0.38 ppm F. Variations in analytical methods make it difficult to compare data reported in different studies. However, the findings in the present study indicate that formula manufacturers have made substantial progress in controlling the fluoride content of their products as the highest reported value was approximately half those reported in studies published prior to 1980. These findings are consistent with similar data reported on a smaller

[4] Tinanoff et al. 1981; Feigal 1983; Balasubramanian 1981; Libo 1981.

TABLE 4. Comparison of Mean Fluoride Concentrations (ppm F^-) Among Formula Types

		P value
1. Ready-to-Feed	.21 ± .08	(1) vs (2) .001
2. Concentrate	.10 ± .07	(1) vs (3) .001
3. Powder	.12 ± .07	(2) vs (3) NS

NS not significant

TABLE 5. Comparison of Mean Fluoride Concentrations (ppm F^-) Between Soy-Based and Milk-Based Formulas

	Soy	Milk	P Value
1. Ready-to-Feed	.24 ± .07	.19 ± .08	NS
2. Concentrate	.16 ± .08	.07 ± .03	.001
3. Powder	.20 ± .02	.08 ± .04	.001

NS not significant

range of samples and products by Singer and Ophaug (personal communication, 1985) and by McKnight et al. (1985).

There was still considerable variation among samples of some individual products collected from various locations. Telephone conversations with representatives of 2 companies that manufacture products with larger-than-average variations in fluoride content indicated that the variations are indeed due to changes in the fluoride content of the water used in processing. It is intended that the fluoridated water supplied to the plants be deionized to reduce the fluoride concentration to 0.2 ppm. However, the concentration may at times rise to 0.4 ppm. The mean fluoride content of ready-to-feed formulas was approximately twice that of concentrated or powdered formulas diluted with deionized water ($P < 0.001$). The explanation for such differences in fluoride content in those 2 forms of formula (i.e., ready-to-feed vs. concentrated or powdered) lies in the fact that the concentrated and powdered formulas are made with less water to begin with.

The mean fluoride concentration for soy-based formulas was higher than for milk-based formulas regardless of product type (ready-to-feed, concentrated, or powdered), but the differences were statistically significant only for concentrated and powdered types. These data are consistent with those reported by Adair and Wei (1978) and more recently by McKnight et al. (1985) on samples collected in Iowa City and in Rochester, New York, respectively. The endogenous levels of fluoride in the ingredients (i.e., soy protein isolate and carbohydrate sources) used in soy formulas are typically higher than those found in the counterpart ingredients used in milk-based formulas.[5]

The dilution of concentrated and powdered formulas collected in Chapel Hill with fluoridated water resulted in predictable increases in fluoride content. Nearly all (92–100%) of the fluoride added in the water was recovered using the analytic method previously described. Thus, it is possible to estimate accurately the fluoride content of all samples of concentrated and powdered products when water of known fluoride concentration is used for dilution. Individual assays were unnecessary.

The findings reported here prompt reconsideration of the recommendation that children who drink ready-to-feed formulas or who drink concentrated or powdered formulas diluted with nonfluoridated water not be given fluoride supplements. The typical fluoride content of such formulas seems to be maintained at a level that should not be of concern with respect to fluorosis when combined with a supplement. The authors estimate that a child drinking a ready-to-feed formula will consume 0.02–0.05 mg F/kg of body weight per day. Infants drinking diluted concentrated or powdered formulas will consume 0.01–0.03 mg F/kg body weight. An additional supplement of 0.25 mg F per day would approximate the accepted optimum daily uptake of 0.05–0.07 mg F/kg body weight.[6]

There have been reports that suggest that mild fluorosis has increased in children over that observed several decades ago, even in areas where the fluoride content in the water is low.[7] This concern coupled with the relatively high fluoride content of formulas reported in the late seventies and the possible ingestion of fluoridated toothpastes by young children apparently reinforced the recommendation not to supplement children in the first 6 months after birth. It is unclear as to why this reduces the risk of fluorosis because the timing of the fluorosis defect has not been definitively established. A recent study by Den Besten and Crenshaw (1984) indicates that the effect resulting from chronic exposure to high fluoride intake is a relative hypomineralization and is manifested during the maturation (rapid mineralization) stage of enamel formation when there is normally a rapid loss of enamel matrix proteins. It appears that fluorosis results from a relatively incomplete removal of the matrix proteins. Crenshaw and Bawden (1984) have published data that indicate that elevated fluoride levels may indirectly partially inhibit the protease that hydrolyzes the matrix proteins prior to their removal from the mineralizing enamel. These observations are consistent with the report by Richards et al. (1985) wherein fluorosis was produced in pig enamel by chronic exposure to increased fluoride intake only during the maturation stage of enamel formation. This observation does not preclude the possibility that fluorosis also can be produced by exposure to high fluoride intake during the secretory (early) stage of enamel formation. But, it is difficult to justify reducing fluoride intake during early enamel formation in anterior permanent teeth and not during the later (maturation) stage if one is concerned about fluorosis.

The chronology of enamel development in the primary dentition has been described in general terms which do not relate to specific stages of enamel formation (Lunt and Law 1974). Deutsch et al. (1984) have presented data on the definitive stages of enamel formation in primary teeth at birth. The primary incisors clearly have progressed to the maturation stage over most of the crown at birth. However, the sample size is too small to establish norms for the postnatal

[5] Miguel SG: Director, Nutritional Medical Affairs, Mead Johnson Nutritional Group, Evansville, Indiana. Personal communication 1986.

[6] Farkas and Farkas 1974; Forrester and Schultz eds 1974.

[7] Leverett and Levy 1982; Aasenden and Peebles 1974; Forsman 1977.

chronology of enamel development in the primary dentition. No data have been published on the definitive stages of enamel formation in permanent teeth at given ages.

It is clear that fluorosis can be produced by exposure to chronic high levels of fluoride intake only during the maturation stage of enamel development (Richards et al. 1985). It is not known if such exposure only during the secretory stage of enamel formation will result in fluorosis. Considering that the timing of the maturation stage in anterior human teeth has not been established, it may be that the critical time for development of fluorosis in these teeth is in the second or third year rather than in the first 6 months or year of life. A recent study showed that, while fluoride uptake can occur in both the early and late stages of enamel formation in rat molars, the earlier the fluoride doses were begun, the higher was the fluoride content near the end of enamel formation (Bawden et al. 1986). The implications of these findings with respect to fluorosis is unclear.

Conclusions

The results of this study indicate that the manufacturers of infant formulas have reduced the relatively high fluoride concentrations reported in some products prior to 1980. The highest concentration found in the products tested was 0.38 ppm. The amount of fluoride in such products appears to be of less concern than in the late 1970s.

This study was supported in part by NIH grant RR05333. The authors thank Thomas G. Deaton and Debra Timko for their technical advisory support and Drs. A.D. Dixon, P.K. Domoto, L. Singer, S. Moss, D. Wilson, and Mr. and Mrs. Johnny Johnson for their help in collecting samples of infant formula.

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Aasenden R, Peebles TC: Effects of fluoride supplementation from birth on human deciduous and permanent teeth. Arch Oral Biol 19:321-26, 1974.

Adair SM, Wei SHY: Supplemental fluoride recommendations for infants based on dietary fluoride intake. Caries Res 12:76-82, 1978.

Balasubramanian M: Question about fluoride in formulas (letter). Pediatrics 66:572, 1981.

Bawden JW, McLean P, Deaton TG: Fluoride uptake and retention at various stages of rat molar enamel development. J Dent Res 65:34-38, 1986.

Crenshaw MA, Bawden JW: Proteolytic activity in embryonic bovine secretory enamel, in Tooth Enamel IV, Fearnhead RW, Suga S, eds. New York; Elsevier Science Publishers, 1984 pp 109-13.

Den Besten PA, Crenshaw MA: The effects of chronic high fluoride levels on forming enamel in the rat. Arch Oral Biol 29:675-79, 1984.

Deutsch D, Shapira L, Alayof A, Leviel D, Yoeli Z, Arad A: Protein and mineral changes during prenatal and postnatal development and mineralization of human deciduous enamel, in Tooth Enamel IV, Fearnhead RW, Suga S, eds. New York; Elsevier Science Publishers, 1984 pp 234-39.

Farkas CS, Farkas EJ: Potential effect of food processing of the fluoride content of infant foods. Sci Total Environ 2:399-405, 1974.

Feigal RJ: Recent modifications in the use of fluorides for children. Northwest Dent 62:19-21, 1983.

Forrester DJ, Schultz EM, eds: Proceedings of the international workshop on fluorides and dental caries reduction. Baltimore; University of Maryland, 1974.

Forsman B: Early supply of fluoride and enamel fluorosis. Scand J Dent Res 85:22-30, 1977.

Leverett DH, Levy D: Presentation, European Organization for Caries Research, Annapolis, Maryland, July 2, 1982.

Libo HW: Breast feeding and fluoride (letter). Pediatrics 66:572, 1981.

Lunt RC, Law DB: A review of the chronology of calcification of the deciduous teeth. J Am Dent Assoc 89:599-606, 1974.

McKnight C, Leverett DH, Adair SM, Shields CP: Fluoride content of milk-based and soy-based infant formulas. J Dent Res 64: 1075, 1985 (abstr).

Richards A, Kragstrup J, Josephsen K, Fejerskov O: Dental fluorosis developed during stage of enamel maturation. J Dent Res 64: 301, 1985 (abstr).

Singer L, Ophaug R: Total fluoride intake of infants. Pediatrics 63: 460-66, 1979.

Taves DR: Determination of submicromolar concentrations of fluoride in biological samples. Talentia 15:1015-23, 1968.

Tinanoff N, Mueller B: Fluoride content in milk and formula for infants. J Dent Child 45:53-55, 1978.

Tinanoff N, Pinkerton R, Ramanan C: Connecticut physicians role in preventing dental caries. Conn Med 45:141-43, 1981.

Whitford GM, Reynolds KE: Plasma and developing enamel fluoride concentration during chronic acid-base disturbances. J Dent Res 58:2058-65, 1979.

Wiatrowski E, Kramer L, Osis D, Spencer H: Dietary fluoride intake of infants. Pediatrics 55:517-22, 1959.