Seasonal Variation in Fluoride Intake: the Iowa Fluoride Study

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Abstract

Objectives: *Although patterns of fluid intake change seasonally, little is known about how fluoride intake varies by season. Since even short-term increases in fluoride intake could potentially lead to more dental fluorosis, it is valuable to assess the degree of seasonal variation to determine if it increases fluoride intake to levels that could be considered a concern in young children.* ***Methods:*** *Questionnaires were mailed periodically to participants in the Iowa Fluoride Study beginning at 6 weeks of age and continuing for a number of years. Parents recorded the date; child's weight; estimates of the amounts of water and other beverages that their child consumed per week; the type and amount of any fluoride supplements used; and the type, amount, and frequency of dentifrice used, with an estimate of the proportion of dentifrice that was swallowed. Documented water fluoride levels from municipal sources and assay of individual sources were linked to water intake amounts. Total fluoride intake per kg body weight was estimated from water, other beverages, fluoride supplements, and ingested dentifrice. Generalized linear models compared temperature-related and seasonal effects after adjusting for the child's age.* ***Results:*** *Separate analyses for ages 0–12 months and 12–72 months showed different results. Children younger than 12 months of age did not exhibit significant seasonal or temperature-related variation in any of the components of fluoride intake. Children aged 12–72 months had higher fluoride intake (mg F/kg bw) from beverages in summer (P<.05), and fluoride intake from beverages increased with monthly temperature (P<.001).* ***Conclusions:*** *Fluoride intake from beverages for children aged 12–72 months is slightly higher in the summer and increases with mean monthly temperature. Fluoride intake from supplements and dentifrice did not change significantly with either season or temperature. [J Public Health Dent 2004;64(4):198-204]*

Key Words: fluoride, children, seasonal variation.

Early fluoride investigators, in trying to determine the appropriate fluoride levels for community water fluoridation, noted that water consumption levels were influenced by climate (1). In the 1950s, Galagan and colleagues published a series of reports (2-4) concerning water consumption and temperature that culminated in the derivation of the following equation to calculate the appropriate level of fluoride for a particular area: ppm F=0.34/(–0.038+ 0.0062 x mean maximum temperature, °F) (5). This equation recommended that 1.0 part per million fluoride (ppm F) was the appropriate fluoride level for the Chicago area (similar in climate to Iowa), where the mean maximum temperature was 61.6°F.

The 1950s research led to the 1962 water fluoridation guidelines (6), which are the basis of the current guidelines (7). The recommended levels for water fluoridation in the United States range from 0.7 to 1.2 ppm F, depending on the mean maximum daily temperature for the area. Colder climate areas (such as in Vermont, Minnesota, and North Dakota) fluoridate their water in the 1–1.2 ppm F range, while warmer areas (such as in Florida, Texas, and southern California) fluoridate in the 0.7–0.8 ppm F range.

Previous studies have shown seasonal differences in water intake in Australia (8), in Iran (9), and for southern US children (10), but not in northern England (11) or for nonsouthern US children (10). A study of fluid intake in children related to regional temperatures using the NHANES III data found no significant association (12).

The Iowa Fluoride Study, now in its 13th year, provides the opportunity to study seasonal changes in fluoride intake for children living primarily in a moderate climate. Iowa mean monthly temperatures over the course of the study ranged from –10°C in December to 25°C in July. The longitudinal design of the study allows assessment of fluoride intake across all months, including separate estimates of fluoride ingestion from beverages (including but not limited to water), dentifrice, and fluoride supplements. While fluoride is an important component of caries prevention, understanding seasonal fluctuations in sources of fluoride could help public health policy makers in reviewing or revising current fluoridation guidelines.

Methods

Sample. This study involved 1,290 children participating in the Iowa Fluoride Study, an ongoing longitudinal study designed to assess fluoride intake, dental habits, and other health measures (13). Mothers and infants were recruited from eight Iowa hospital postpartum wards from 1992 to 1995. Participants were sent detailed questionnaires at regular intervals, beginning at 6 weeks of age. Nonresponders were sent a follow-up mailing after three weeks and again after six weeks. While all children in the study

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were born in Iowa, many moved before the current study's endpoint (age 6 years), including a few who moved to neighboring states, other regions in the United States, or overseas. Those children who moved over the course of the study were included if they returned one or more questionnaires and returned water samples for individual fluoride assays. The University of Iowa's Institutional Review Board approved the use of human subjects in this study.

Data Sources. Questionnaire responses were requested five times during the first year (six weeks, three months, six months, nine months, and 12 months), three times each during each of the next two years (ages 12–36 months), two or three times per year the next two years (ages 36–60 months), and twice per year thereafter. The present study included only returns up to age 72.5 months. Most subjects failed to return at least one questionnaire, but all responses were included in the present study regardless of the subject's questionnaire return frequency. Since the primary unit of analysis for the present study was ingested fluoride per kilogram of body weight (mg F/kg bw), all questionnaires not reporting weight were excluded from the analyses.

Questionnaires asked parents to estimate beverage intake for the preceding week. Instructions for the beverage questionnaire asked parents to provide information on all beverages consumed over the previous week, and provided an example for calculating the ready-to-feed juice/juice drink portion of the questionnaire. For each beverage type (water, formula, milk, juice or juice drinks, nonjuice beverages such as soda pop, and beverages made from powdered concentrates), the amount of water added for reconstitution was estimated. Because the intake questionnaire design remained unchanged, was filled out repeatedly over the course of the study, and the Iowa Fluoride Study staff provided help by phone, most parents were able to provide a reasonable estimate of their child's intake. Parents also indicated whether they were using tap water, bottled water, or both for consumption. Dentifrice ingestion was estimated based on questionnaire items concerning frequency of brushing, amount of dentifrice, brand of dentifrice, and an estimate of the proportion of dentifrice that was swallowed (14). Dentifrice amounts were assessed using a series of seven toothbrush diagrams showing varying amounts of dentifrice from about 0.0625 mg F to 1.0 mg F for 1,000–1,100 ppm fluoride dentifrice (20). Parents estimated the proportion of dentifrice that was swallowed by their child on a seven-point scale ranging from "all" to "none at all." Fluoride ingestion levels for supplements were estimated using questionnaire items asking whether or not the child used a fluoride supplement, details of the product, dosage, and frequency of use (15). The child's weight was reported by parents in pounds, and converted to kilograms.

Tap water samples were either individually assayed (all from wells and filtered sources) or linked to documented fluoride levels of community water sources (unfiltered only). Bottled waters were assayed by brand name, product, and container size. Other ready-to-feed beverages and beverage concentrates were assayed (16,17) and an overall estimate of average fluoride level was assigned for each type of beverage (milk, formula, juice or juice drinks, carbonated beverages or sports drinks, and powdered beverage mixes). Fluoride estimates for beverages made from liquid or powdered concentrates added individual water fluoride estimates to the assayed fluoride estimate of the purchased concentrate. Although purchased products had considerable variability in fluoride content, to get a more precise estimate we would have needed information from each family on specific products used, brands, and production location for each product. Obtaining such complete information at that level of detail was not feasible, so we used global estimates that were averaged over the most frequently used products.

Mean monthly temperatures (°C) for the state of Iowa were recorded for each month in which questionnaires were returned. Iowa climatic information was obtained from the National Climatic Data Center (18) Web site. All questionnaire data were double entered and verified. All data were converted to SAS (19) data sets and merged for data analysis.

Response Variables. Combined fluoride intake was estimated from three major sources: beverages, dentifrice, and dietary supplements. Fluoride intake from beverages combined estimates from water alone (tap and bottled), water added to beverages or concentrates, and other beverages or concentrates (ready-to-feed drinks, liquid concentrates, or powdered concentrates). Fluoride intake from dentifrice was estimated by multiplying the frequency of use per day, the dentifrice fluoride concentration, the amount of dentifrice used, and the estimated proportion of dentifrice that was swallowed. And lastly, fluoride intake from supplements (either drops or tablets) was estimated from individual supplement fluoride concentration and frequency of use. Combined fluoride intake and each of its three components were standardized, dividing each by the child's weight (kg). If any of the three fluoride components or the child's weight was missing on a returned questionnaire, then the child's fluoride intake was excluded for that time point.

Explanatory Variables. Since fluoride intake per kg body weight tends to decrease with age, all regression analyses included the age of the child (in months) based on the date of the returned questionnaire. The calendar month of each returned questionnaire was used to categorize each return as "summer" (June, July, August), "fall" (September, October, November), "winter" (December, January, February) or "spring" (March, April, May). Since Iowa seasons differ in both temperature and activity level (summer is hotter and outdoor activity increases), we further paired each return with a mean monthly temperature (°C) according to the questionnaire date and Iowa temperature records from the NCDC Web site (18). The child's sex was also included in all initial regression analyses.

Statistical Methods. Due to substantial changes in diet that generally occur around the age of 12 months, separate analyses were conducted for the first year of life versus ages 12 to 72 months. The first year of life is generally characterized by a diet of formula (potentially high in fluoride levels), with other beverages and foods being gradually introduced. After 12 months of age, children generally switch to milk (with very little fluoride) and add increasing amounts of other beverages and foods. Seasonal effects on fluoride intake during the first 12 months would also be expected to be minimal since outdoor activity is very limited at that age. Franzman et al. (20) have shown that toothbrushing habits in this cohort became established between 6 months of age (29% of subjects brushing) and 20 months (97% of subjects brushing). Therefore, fluoride (mg/kg body weight) from ingested dentifrice was modeled in two separate linear pieces, with 12 to 24 months exhibiting an increasing trend, *but 24 to 72 months showing* a decreasing trend.

Generalized linear models using SAS Proc GENMOD were used to separately assess trends in components of fluoride intake for children aged 0–12 months and children aged 12–72 months. Seasonal trends in fluoride supplement intake were not assessed since so few children used them (91.5% of all returns reported no fluoride supplement use). All analyses began with inclusion of age (in months), sex, season (summer, fall, winter, spring), and average monthly temperature (Iowa). All models used a repeated measures design with an exchangeable correlation structure (compound symmetry) and an identity link function. Backward elimination was used to eliminate nonsignificant ($P>.05$) effects until all remaining effects were significant at the .05 level. Two-way interaction effects were tested for all pairs of significant main effects ($P<.05$).

Results

Sample Characteristics. Of the 1,290 participants in the present study, only 4 percent had mothers of a minority race (96% were white), 44 percent were the first child in the family, and 61 percent had family incomes above $30,000 per year at recruitment. Educational levels for both mothers and fathers were high, with 61 percent of mothers and 67 percent of fathers having at least some college education. Fluoride levels for individual water sources averaged 0.79 ppm for all responses (averaged over home water source, child care source and bottled water source, if used), and ranged from 0 to 3.99 ppm overall. Questionnaire returns decreased over time as the study progressed, with 99 percent of our subjects returning questionnaires during the first year, and 63 percent, 56 percent, 52 percent, 51 percent, and 46 percent, respectively, for the second through sixth years.

FIGURE 1
Average Daily Fluoride Intake Adjusted for Body Weight

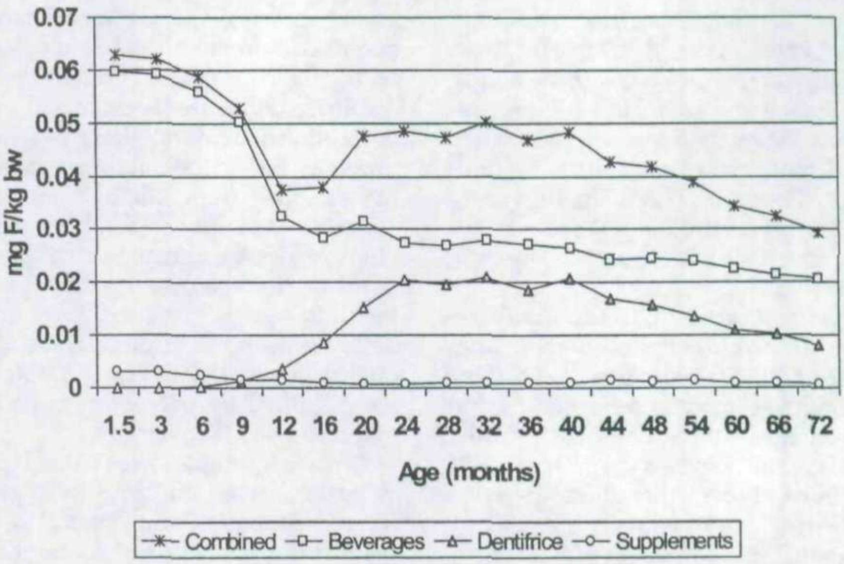
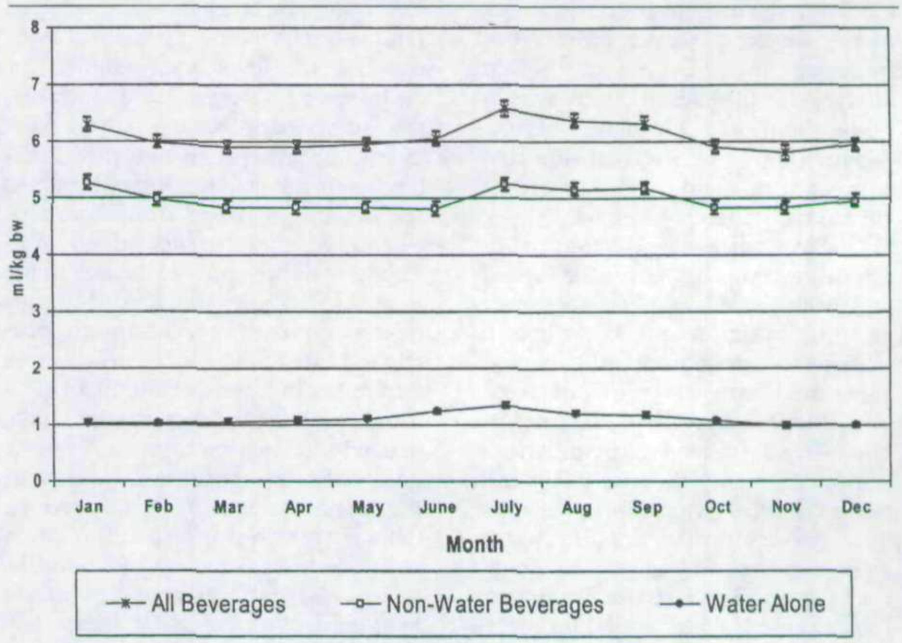


FIGURE 2
Average Daily Intake of Beverages (ml) Adjusted by Body Weight (±SE), Children Aged 12–72 Months



Bivariate Analyses. Fluoride intakes by age (adjusted for body weight) from each of the three sources (beverages, dentifrice and supplements) and combined are presented in Figure 1. Changes in fluoride intake from beverages at the end of the first year can be attributed mainly to decreases in formula consumption and increases in milk consumption. After the first year, weight-adjusted fluoride intake from beverages declined more gradually, with weight increasing slightly faster than fluoride intake from beverages. Mean fluoride ingestion from dentifrice was negligible during the first 12 months, but increased from 12 to 24 months as more children began brushing routinely with fluoridated dentifrice. Decreases in fluoride ingested from dentifrice after 40 months can be partially attributed to gains in body weight, but also could be partially explained by children becoming more adept at spitting out dentifrice when brushing. Figure 1 shows that there were two distinct periods with elevated mean fluoride in-

FIGURE 3
Average Daily Intake Adjusted by Body Weight (±SE), Children Aged 12–72 Months

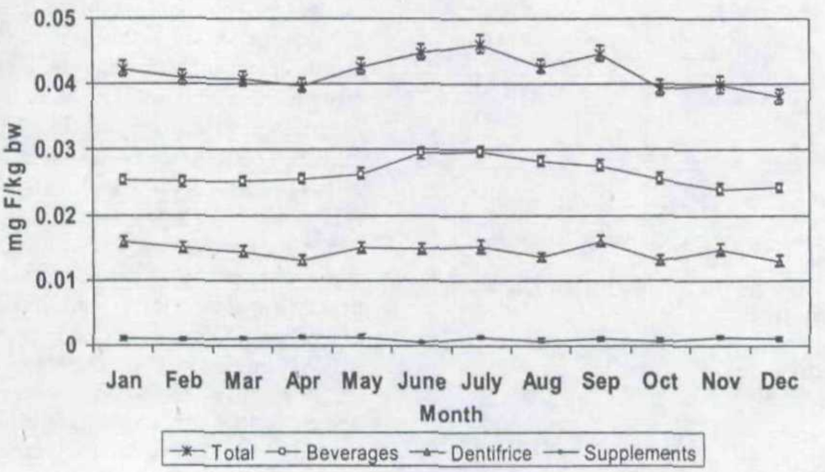


FIGURE 4
Average Daily Beverage Intake Adjusted by Body Weight (±SE), Children Aged 12–72 Months

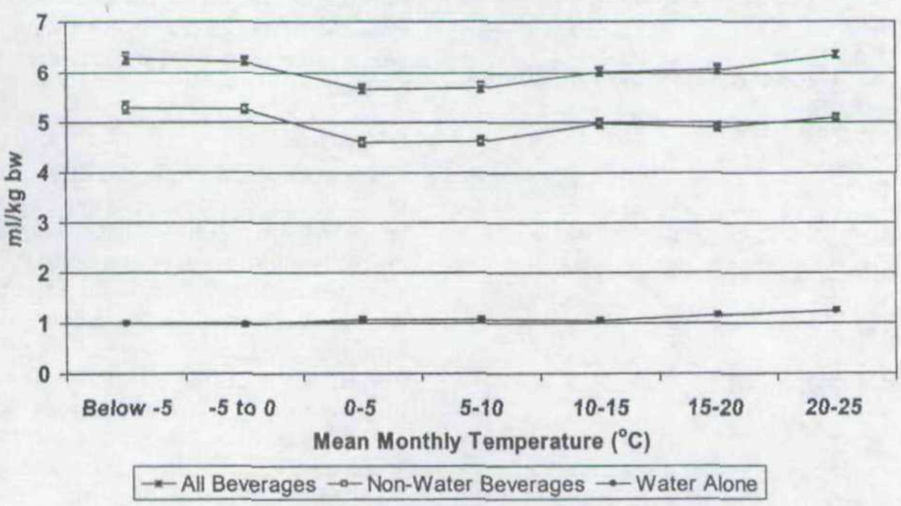
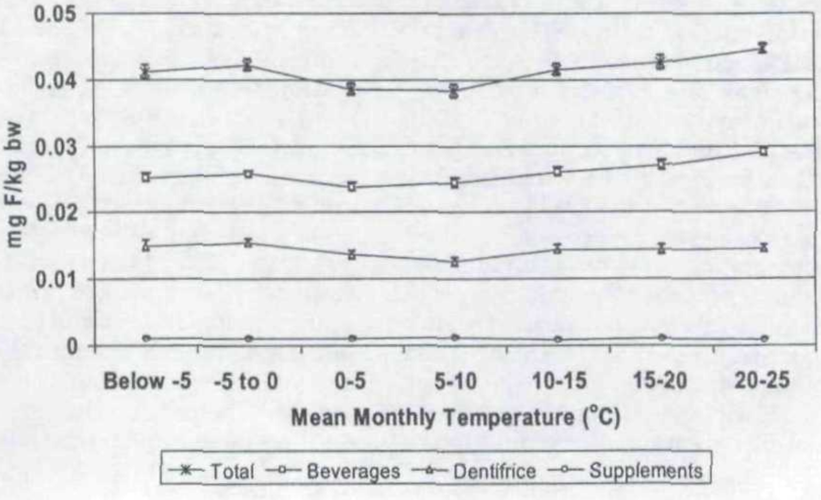


FIGURE 5
Average Daily Fluoride Intake Adjusted by Body Weight (±SE), Children Aged 12–72 Months



take, the first one during ages 1.5–9 months and the second occurring from ages 20–40 months. For a more thorough description of sources of fluoride intake for this sample of children, see Levy et al. (13,21).

Since seasonal fluctuations in fluoride intake would reasonably be expected to mimic seasonal fluctuations in beverage intake, we first plotted average daily beverage intake (ml/kg) by calendar month. Although average beverage intake for children aged 0–12 months was fairly stable by month (data not shown), Figure 2 shows that average water intake for children aged 12–72 months peaked in the summer months, and that average intake from other beverages was high July through September and also in January.

We proceeded with our investigation of seasonal changes in fluoride intake by plotting average fluoride intake (mg/kg per day) by calendar month. Fluoride intake during the first year was analyzed separately and did not exhibit any seasonal or temperature-related trends. Figure 3 shows average monthly fluoride intake per kg body weight for children age 12 to 72 months. No significant trends were apparent in fluoride intake from dentifrice or supplements, but fluoride intake from beverages was highest in June through September.

Since average beverage intake (ml/kg) fluctuated by calendar month for 12–72-month-old children, we also looked at temperature trends. Figure 4 shows a slight increase in average water consumption with higher temperatures, but more notable are the differences in average nonwater beverage intake (milk, juice and juice-flavored drinks, sports beverages, and soda pop). Nonwater beverage intake was highest in the coldest months (0°C and below), but then dropped to 4.6 ml/kg bw at 0–5°C and increased gradually as temperatures rose to 5.1 ml/kg bw at 20–25°C.

Average fluoride intake per kg body weight is plotted by average monthly temperature in Figure 5. Again, intakes for ages 0 to 12 months were excluded since no discernible trends by temperature were found at those early ages. Variation in fluoride intake from supplements by monthly temperature was negligible, but fluoride from dentifrice and beverages both showed change across temperature categories. While fluoride from

TABLE 1
Predicting Beverage Fluoride Intake (mg F per kg body weight) for Children Aged 0–12 Months

	Parameter Estimate	Standard Error	Z	Pr>|Z|
Intercept	0.0633	0.0024	26.06	<0.0001
Age (months)	–0.0010	0.0003	–3.73	0.0002

TABLE 2
Predicting Beverage Fluoride Intake (mg F per kg body weight) for Children Aged 12–72 Months

	Parameter Estimate	Standard Error	Z	Pr>|Z|
Intercept	0.0321	0.0007	43.56	<0.0001
Age (months)	–0.0002	<0.0001	–12.15	<0.0001
Temperature (°C)	0.0001	<0.0001	4.70	<0.0001
Summer	0.0013	0.0006	2.19	0.0289

TABLE 3
Predicting Fluoride Intake (mg F per kg body weight) from Dentifrice, Children Aged 12–72 Months

	Parameter Estimate	Standard Error	Z	Pr>|Z|
Intercept	0.0281	0.0012	23.08	<0.0001
Under 24 months	–0.0436	0.0023	–19.23	<0.0001
Age (months)	–0.0003	0.0001	–12.55	<0.0001
Age X Under 24 mos.	0.0018	0.0001	14.98	<0.0001

beverages tended to increase with temperature (with a slight exception for the coldest months), the drop in fluoride ingested from dentifrice over the cool months (0-5°C and 5-10°C) is more puzzling.

Multivariable Analyses. Generalized linear models were used to assess relationships between fluoride intake per kg body weight and multiple independent variables. All seasonal and temperature effects were negligible for beverage intake per kg body weight during the first year. Only the child's age (mg F/kg bw declined with age) remained in the final model (Table 1).

Table 2 shows that seasonal effects were found in fluoride intake from beverages (per kg bw) for children aged 12–72 months. Beverage fluoride intake per kg body weight decreased with age, increased with outdoor temperature, and also was higher during the summer months. However, an increase of 5°C during the summer only increased the mean estimate of fluoride intake/kg bw by 0.0018 mg F per kg body weight $(0.0013+5*0.0001)$. Additional adjustments for January and for temperatures below zero were not significant. None of the two-way interactions were significant (P>.05). The GEE model tests only effects on mean fluoride intake across subjects. That means that some subjects would show negative changes with increased temperatures and onset of summer, while others might undergo more substantial positive increases. For this sample, 25 percent of subjects had summer increases of 0.01 mg F/kg bw or greater, and the maximum individual increase in summer fluoride intake was 0.12 mg F/kg body weight.

Fluoride ingestion from dentifrice was not modeled for children aged 0 to 12 months because toothbrushing habits were not well established before 12 months of age. Preliminary GEE models for fluoride intake per kg body weight from dentifrice at 12–72 months included both linear and quadratic effects for temperature since initial plots indicated declines for mid-range temperatures and inclines at either extreme. Also, linear effects for age were split into two sections, one preceding 24 months and the other afterward. The split at 24 months allowed the model to increase from 12–24 months when children were increasing toothbrushing frequency, and allowed the model to decrease after 24 months (Table 3). Both age effects were significant; however, all other seasonal and temperature effects were not significant. The significant two-way interaction indicates that fluoride intake per kg bw from dentifrice increases with age up to age 2 years, but after this begins to decrease with age.

Discussion

The recruited sample appears to be generally representative of the population in Iowa in terms of race, income, and education, but mothers who were younger and less educated tended to drop out sooner. The Iowa Fluoride Study is conducive to a simple study design, not requiring complex weighting schemes for different regions, socioeconomic or ethnic groups, but the results should not be generalized to more diverse populations that may have quite different patterns of fluid intake.

Most Iowa communities have water fluoridation; however, rural residents generally have individual wells that often have very low fluoride levels, but can have very high or moderate fluoride levels. Of all responses in the Iowa Fluoride Study up to age 72 months, 26 percent had home water sources with less than 0.60 parts per million (ppm) fluoride, 67 percent had home water sources ranging from 0.60 to 1.20 ppm, and 7 percent had home water sources above 1.20 ppm. However, even for families with low levels of fluoride in their home water, children often drank purchased beverages that were bottled in other communities, and those communities often had fluoridated water. Previous studies have concentrated on analyzing water intake for communities of differing fluoride levels (9), water and fluid intake across the US (10,12), fluoride intake for communities of differing fluoride levels (22), and cross-sectional fluoride intake for multiple regions and ages (23). The present study benefited from being able to estimate ingested fluoride from amount of beverage intake, home water fluoride levels, and child care water fluoride levels for each subject individually and over multiple time points.

Optimal water fluoride concentrations proposed by Galagan and Vermillion (5) acknowledge the effect of external temperature on the amount of water consumed. Present application of the formula, however, does not provide for seasonal variation within a region, even though daily temperatures can change markedly. Zohouri and Rugg-Gunn (9) showed substantially higher fluoride intake during summer in Iran, where temperatures ranged from –5°C to 40°C (23°F to 104°F) over the year. In summer, average fluoride intake of 4-year-old children increased 0.04 mg/day (compared to winter) for the region with water fluoridation at 0.6 ppm, and 0.65 mg/day for the region with 4.0 ppm. In Iowa (where most municipal water sources are fluoridated at 1.0 ppm), average daily summer temperatures only rise about 22°F over spring and fall temperatures, but public water fluoridation levels remain constant. Sohn et al. (12) did not find a significant linear relationship between fluid intake and temperature, but used mean temperatures over a 30-year span that were not specifically linked to the year in which the data were collected. Further complications arose because the NHANES III data were collected in multiple and diverse regions of the United States Since the Iowa Fluoride Study is longitudinal, subjects mainly resided within the state of Iowa, and we were able to match specific Iowa monthly mean temperatures to each of the questionnaires, the current study was able to reduce standard errors to the point where statistical significance was achieved.

In the Iowa Fluoride Study cohort, fluoride intake from beverages increased over the summer months, showing a significant association with mean monthly temperature. In addition, increases in fluoride intake over the summer months beyond what would be predicted from external temperature and child's age (Table 2) were found. This additional "summer" effect could possibly be attributed to several factors. The generally higher temperatures of summer might lead to an increase in perspiration, an increase in thirst, and an increase in fluid consumption. This effect could be magnified in the summer (when school is not in session) since children tend to spend more time in outdoor activities. Children also could be switching to different types of beverages over the summer. Seasonal changes in activity levels, activity types, and beverage types would be interesting topics for future studies.

Figures 4 and 5 show that both average beverage intake and average fluoride intake increase slightly (not significant) for the months with coldest temperatures, suggesting that seasonal variation may be underestimated when comparing only winter to summer. Increases in amounts of nonwater beverages for January (Figure 2) (P>.05), however, reinforce the idea that behavioral changes related to extreme cold weather could lead to increased beverage intake, although the amount of fluoride ingested from beverages remains stable (Figure 3). This suggests that the types of beverages with increased intake could be low in fluoride (e.g., milk).

Previous analysis of Iowa Fluoride Study data from 12 to 20 months of age indicated significant linear and quadratic effects of age on fluoride intake (21). Since a higher proportion of subjects were recruited in late summer and fall, the nonlinear effects found for age could be partially attributable to increases in fluoride intake over the summer months. Subsequent Iowa Fluoride Study analysis of fluoride intake data from 36 to 72 months included adjustment for seasonal effects, but did not study their magnitude (13).

Seasonal increases in fluoride intake during the summer months with warmer temperatures average less than 0.002 mg F per kg body weight; however, individually, 25 percent of subjects showed increases of 0.01 mg F/kg bw or more, which is noteworthy if the child's fluoride intake level is already high. Children aged 20 to 40 months show high levels of fluoride intake (Figure 1) due to a pattern of ingesting substantial amounts of fluoride from dentifrice. It seems impractical to lower community water fluoride levels during summer months to accommodate children of this restricted age range, but promoting lower-fluoride summer-type beverages targeted at preschool age children may be feasible. It would also seem prudent to lower fluoride levels in dentifrice targeted for young children, which could provide more substantial decreases of fluoride intake for the 20–40-month-old children who may be most at risk for developing fluorosis.

In conclusion, the study found small seasonal variation in mean fluoride consumption from beverages, with slightly higher intakes during the summer months. While this variation exists, the magnitude of the variation is quite low, suggesting that seasonal/climatic alterations in water fluoride levels are probably unnecessary.

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