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Considerations on Optimal Fluoride Intake using Dental Fluorosis and Dental Caries Outcomes – A Longitudinal Study

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Abstract

Objectives—The “optimal” intake of fluoride has been widely accepted for decades as between 0.05 and 0.07 mg fluoride per kilogram of body weight but is based on limited scientific evidence. The purpose of this paper is to present longitudinal fluoride intake data for children free of dental fluorosis in the early-erupting permanent dentition and free of dental caries in both the primary and early-erupting permanent teeth as an estimate of optimal fluoride intake.

Methods—Data on fluoride ingestion were obtained from parents of 602 Iowa Fluoride Study children through periodic questionnaires at the ages of 6 weeks, 3, 6, 9, 12, 16, 20, 24, 28, 32 and 36 months, and then at 6-month intervals thereafter. Estimates of total fluoride intake at each time point were made by summing amounts from water, dentifrice, and supplements as well as other foods and beverages made with or containing water. Caries data were obtained from examinations of children at ages 5 and 9 years, while fluorosis data were obtained from examinations only at age 9.

Results—The estimated mean daily fluoride intake for those children with no caries history and no fluorosis at age 9 was at or below 0.05 mgF/kg bw for nearly all time points through the first 48 months of life, and this level declined thereafter. Children with caries had generally slightly less intakes, while those with fluorosis generally had slightly higher intakes.

Conclusions—Given the overlap among caries/fluorosis groups in mean fluoride intake and extreme variability in individual fluoride intakes firmly recommending an “optimal” fluoride intake is problematic.

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Introduction

The “optimal” intake of fluoride **in children** has been widely accepted for decades as between 0.05 and 0.07 mg fluoride per kilogram of body weight (0.05-0.07 mgF/kg bw), although it is not clear whether this level of intake is “optimal” for caries prevention, fluorosis prevention, or a combination of both. (1). Moreover, the basis for this estimate is largely from data originally obtained in the 1930s and 1940s by McClure (2), when there were no dental fluoride products available and limited understanding of how fluoride worked to prevent dental caries. Additionally, the scientific evidence of what constitutes “optimal” fluoride intake is mostly based on fluoride intake to minimize dental caries prevalence in areas with optimally fluoridated water, and generally does not consider either topical fluorides (e.g., dentifrice) or prevention of dental fluorosis.

As has been described in previous articles(1-5), McClure (2) estimated children's fluoride intake from **1ppm fluoride** water and **food** to be **approximately** 0.5 to 1.5 mg per day based on data from the studies of Dean et al (3,4). Given that children's weight increases with age, based on average weights of children up to age 12, McClure estimated that “as a general rule” fluoride intake corresponding to consumption of 1.0 ppm water fluoride was about 0.05 mg per kilogram of body weight (2). Apparently because Dean had established 1.0 ppm as the “optimal” water fluoride concentration for caries prevention, McClure's estimates based on consumption of water at 1.0 ppm fluoride came to be considered as the “optimal” level of daily fluoride intake. Over time and based on other assessments of fluoride intake and various expert opinions, the optimal fluoride intake level was refined to the range of 0.05 to 0.07 mgF/kg bw. As such, this “optimal” fluoride intake level is not based on any direct assessment of how such intake relates to the occurrence or severity of dental caries and/or dental fluorosis. A subsequent review continued to emphasize this range as the best estimate of “optimal” fluoride intake, noting these limitations (5)

The purpose of this paper is to present results relating longitudinal fluoride intake data obtained from the ongoing Iowa Fluoride Study to dental caries and dental fluorosis among cohort children. Patterns of estimated longitudinal fluoride intakes for children free of dental fluorosis in the early-erupting permanent dentition at age 9 and free of dental caries in both the primary teeth at age 5 and permanent teeth at age 9 are presented, along with intake estimates for children with one or both of these conditions. Specifically, the purpose of these analyses is to relate longitudinal fluoride intake to optimal oral health, defined as being free of fluorosis in the permanent teeth, and free of caries in both the primary and permanent teeth.

Materials and Methods

The Iowa Fluoride Study is a longitudinal cohort study of children recruited just after birth from 8 Iowa hospitals during the period from March 1992 to February 1995 (7-**14**). Initially, 1,882 were recruited, but 493 did not respond to follow-up contacts, so that the participating cohort consisted of 1,389 infants. The study is ongoing, and currently approximately 607 children remain in the cohort at age 13 to 16 years.

Data on fluoride ingestion were obtained from periodic questionnaires sent to parents when their children reached the ages of 6 weeks, 3, 6, 9, 12, 16, 20, 24, 28, 32 and 36 months, and then at 6-month intervals thereafter (**6-14**). The questionnaires asked detailed questions about fluoride exposures and ingestion, including estimated amounts and specific sources during the previous week (6,7). The main sources were water, including water by itself and water used to reconstitute beverages that included infant formula at home, child-care and school; fluoride dentifrice; and dietary fluoride supplements (7,8). Questions concerning quantities and frequency of ingestion of foods made with water (such as rice and pasta), as well as questions regarding bottled water consumption, were also included in the questionnaires, as were questions about ready-to-drink beverage consumption (6,7). Parents were also asked to report the child's height and weight on each questionnaire.

Reliability assessments were conducted for fluoride intake questionnaires 7-10 days after the initial questionnaires were returned. Percentage agreement for questions concerning water filtration were 95% (kappa=0.81), concerning primary water source was 91% (kappa=0.77), concerning the use of dietary fluoride supplements was 99% (kappa=0.97), concerning toothbrushing frequency was 86% (kappa=0.79), and concerning use of dentifrice was 92% (kappa=0.48).

Home, child care and school water fluoride concentrations were determined via a database of community water fluoride concentrations maintained by the State of Iowa for sources on community water supplies, and by testing individual well or filtered water samples using a fluoride-specific electrode (7). Similarly, ready-to-drink beverages reported to be consumed by the study cohort were purchased by study staff and tested for fluoride concentration (9,10).

Questions about frequency of dentifrice use, brand, quantity used (as determined by having parents selecting pictures of toothbrushes with different amounts of toothpaste), and estimates from parents on the proportion of dentifrice ingested were used to determine fluoride intake from dentifrice. A database of specific fluoride products (dentifrice and supplements) was developed with the fluoride concentrations determined from the label or via pharmaceutical reference (8,11).

Individual fluoride ingestion was estimated for each individual at each time point by determining intake for each product (amount consumed x concentration) and converting this to a daily average based on frequency of intake. The estimated daily total fluoride intake was then computed by summing the intakes from all individual sources – water by itself, water added to reconstitute beverages, other beverages, selected foods made with water, dentifrice and supplements. The estimated fluoride intake per unit body weight was determined using the child's weight as reported on each questionnaire (12,13).

Dental examinations, including assessments of dental fluorosis and dental caries, were conducted on cohort children at the targeted ages of approximately age 5 (mean age = 5.2 years) and again at approximately age 9 (mean age = 9.3 years). The examinations were conducted by two trained and calibrated examiners using halogen headlights and portable dental chairs. Dental caries examinations at both time points included assessment of noncavitated and cavitated lesions using criteria specifically developed for the project (14). In brief, the examinations were primarily visual using compressed air to diagnose caries, but a shepherd's hook explorer was used to confirm cavitated lesions. Non-cavitated (d-1/D-1) lesions were those that presented with a chalky white appearance on smooth surfaces or surrounding pits or fissures. Cavitated lesions (d-2+/D-2+) were those which displayed demonstrable loss of enamel (with or without dentinal involvement) or exhibited softness at the base of the lesion upon explorer probing (14), similar to traditional DMF assessments.

Fluorosis assessments were made by two trained and calibrated dentist examiners of the permanent incisors and first molars at age 9 using the Fluorosis Risk Index (15). For the present analyses, fluorosis cases were considered as those having at least one permanent incisor or first molar affected by definitive fluorosis (i.e., with FRI scores of 2 or 3).

For this analysis, the sample included those who received dental examinations as part of the study at approximately age 5 and again at approximately age 9. The individuals were placed into 4 groups based on their caries/fluorosis status as follows: 1) no fluorosis at age 9 and no caries at either age 5 or age 9; 2) fluorosis at age 9, but no caries at either age 5 or age 9; 3) no fluorosis at age 9, but caries at either age 5 or age 9; and 4) both fluorosis at age 9 and caries at either age 5 or age 9. For these children, mean estimated combined daily fluoride intake for each time point from age 6 weeks through 8.5 years is reported. Because the child's age when the questionnaires were completed differed from the targeted age by several days to several weeks, the exact time points reported were standardized by interpolating the fluoride intake estimates from previous and subsequent responses for each individual child.

Results

A total of 601 children received both dental examinations and thus met the inclusion criteria for this analysis. Of these, 153 had neither fluorosis at age 9 or caries experience at age 5 or age 9; 202 had caries at one or both exams, but no fluorosis at age 9; 96 had fluorosis at age 9, but no caries at either exam; and 150 had both fluorosis at age 9 and caries at one or both exams.

As demonstrated in Figure 1, the estimated mean daily fluoride intake for those children with no caries history and no fluorosis at age 9 was at or below 0.05 mgF/kg bw for nearly all time points through the first 48 months of life (except for a single time point at 6 months of age), and this level declined thereafter. Note that those with fluorosis, either alone or also with caries history, had consistently higher mean fluoride intake levels over the first 4 years of life, while the mean fluoride intakes of those with caries only closely mirrored, but were slightly less than, the intakes of those with neither caries or fluorosis.

While Figure 1 demonstrates that the mean fluoride intake of those with neither caries history nor fluorosis was less than 0.05 mgF/kg bw at virtually all time points, there was considerable individual variation. Figure 2 shows the individual data points for fluoride intakes for those children with neither fluorosis nor caries. As demonstrated in Figure 2, the fluoride intakes of many children without caries or fluorosis greatly exceeded or fell far short of the 0.05 to 0.07 mg F/kg bw “optimal” range at each individual time point.

Discussion

The concept of an “optimal” level of fluoride intake originated with the work of McClure in the 1940s, who stated, “An estimated quantity of water-borne fluorine equal to approximately 0.5 to 1 mg of fluoride daily present in the average diet from the first to eighth year of life appears to be instrumental in reducing dental caries to a great degree......The importance of the preventive effects of **fluorine** on dental caries suggests that serious thought be given to the use of this optimum quantity of supplemental fluoride in children's diets for the partial control of dental caries” (2). In that era, most fluoride intake was from naturally fluoridated water (McClure estimated a range of 67% to 94%), with no fluoride dentifrice, supplements or other fluoride products available (2). Moreover, in that era, it was believed that fluoride needed to be ingested early in life to provide caries prevention (1). Hence, defining an optimal amount of fluoride ingestion from food, water and other beverages may have been appropriate for young children at that time.

Today, evidence suggests that, although there appear to be some benefits from systemic/ingested F (16,17), the benefits of fluoride are mostly topical. Therefore, with widespread water fluoridation and countless fluoride-containing products available, quantifying the intakes of fluoride is much more complex than it was several decades ago. In fact, obtaining data from the Iowa Fluoride Study necessary for estimates of total fluoride intake has been extremely complex. For example, fluoride concentrations varied considerably within the same product category depending on site of manufacture and distribution pattern, and many children utilized multiple sources of water, often varying in fluoride concentration. Similarly, the amount and content of dentifrice used and swallowed was difficult to estimate, and use of fluoride supplements was somewhat sporadic among those using them (7,8,11). Thus, it's doubtful that parents or clinicians could adequately track children's fluoride intake and compare it the recommended level, rendering the concept of an “optimal” or target intake relatively moot.

Perhaps more importantly, the present analysis of Iowa Fluoride Study data demonstrated that there was considerable overlap in mean fluoride intakes among the four groups studied, and as demonstrated in Figure 2, considerable variation in individual intake amounts at the specific time points. The study did find that those free of both caries and fluorosis had mean fluoride intakes of less than 0.05 mgF/kg bw at nearly every time point from birth through age 8.5 years, but also found that the group with fluorosis, but free of caries, had mean intakes mostly higher than the other groups. These findings suggest that achieving a caries-free status may have relatively little to do with fluoride *intake*, while fluorosis is clearly more dependent on fluoride intake.

The findings are generally consistent with other recent estimates of fluoride intake. For example, Guha-Chowdhury et al (18), found that a sample of New Zealand children 3 to 4 years of age residing in areas with optimal water fluoridation had mean fluoride intakes ranging from 0.032 to 0.040 mgF/kg bw when considering fluoride from diet and toothpaste.

A similar study conducted on 1- to 3-year-olds in Indiana and Puerto Rico found mean fluoride intakes of 0.056 and 0.073 mgF/kg bw in non-fluoridated areas of Indiana and Puerto Rico, respectively, while children in a fluoridated Indiana community had mean fluoride intakes of 0.070 mgF/kg bw (19). Both of these studies utilized the duplicate diet approaches to assess fluoride intake, which was different than the questionnaire methods used in the present study. Nonetheless, the present study's finding across all caries/fluorosis groups appears to be consistent with these earlier studies.

While the present study was longitudinal and went to extensive efforts to account for multiple fluoride sources, it relied on periodic parental reports of fluoride use and ingestion, which may not have been completely accurate. In addition, some potential sources of fluoride ingestion, such as fluoride mouth rinses and gels or professional fluoride applications, were not assessed in a way to yield concentrations and amounts of fluoride ingestion. In addition to these limitations, the study was conducted in one area of the United States with a sample that was not representative of any defined population. In part because of the longitudinal study design, those who remained in the study until the dental examinations at age 9 tended to be from higher income families than those who dropped out of the study. Lastly, there were missing data, so that the means reported were based on variable numbers of respondents for each time point.

In addition to the study's limitations, there are a few cautions in interpreting the study results. First, most of the fluorosis was mild or very mild (3% of fluorosis cases were “severe” as defined by FRI score 3), and generally not of much esthetic concern. Similarly, most of the children with caries had relatively few decayed or filled surfaces.

It should be emphasized that while almost all of the fluorosis cases in the present study were mild, the level of esthetic concern among individual cases likely also varied considerably so that, as demonstrated in a previous study (20), an “optimal” fluoride level to avoid fluorosis may differ depending on the threshold used to define fluorosis. This is important because as reported in a recent article (21), mild fluorosis was associated with higher quality of life measures, which suggests that avoiding all fluorosis may not be warranted.

Despite the limitations, the study provides the only recent, outcome-based assessment of the “optimal” fluoride intake, and as such, it appears that while the generally accepted range of 0.05 to 0.07 mgF/kg bw may still be associated with caries prevention, it may not be optimal in preventing fluorosis. Of course, given that most caries prevention is believed to be due to topical exposures, it may be of little consequence as to what the “optimal” fluoride intake level is for caries prevention. By the same token, while limiting fluoride intake to less than 0.05 mgF/kg bw may be appropriate to prevent fluorosis, given that most fluorosis was mild even at higher intake levels, recommendations to limit fluoride intake to less than 0.05 mgF/kg bw may not be justified. Thus, given that the present study found considerable overlap among caries/fluorosis groups in terms of mean fluoride intake and extreme variability in individual fluoride intakes for those with no fluorosis or caries history (Figure 2), firmly recommending an “optimal” fluoride intake is problematic, and as stated by Burt and Eklund, perhaps it is time that “the term optimal fluoride intake be dropped from common usage”(1).

Acknowledgments

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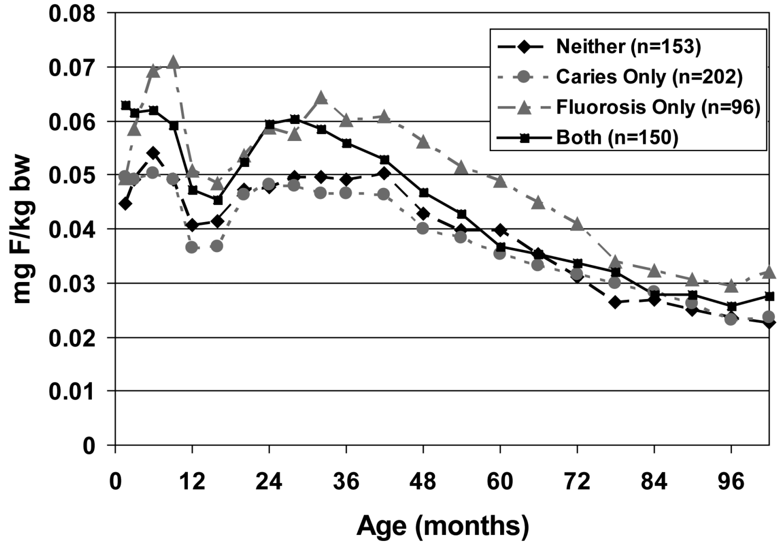

Figure 1.

Mean Daily Combined Fluoride Intake (mg F/kg bw) by Permanent Tooth Fluorosis (Incisors & 1st Molars) and Caries Status (d2+fs or D2+FS>0 at either age 5 or age 9)

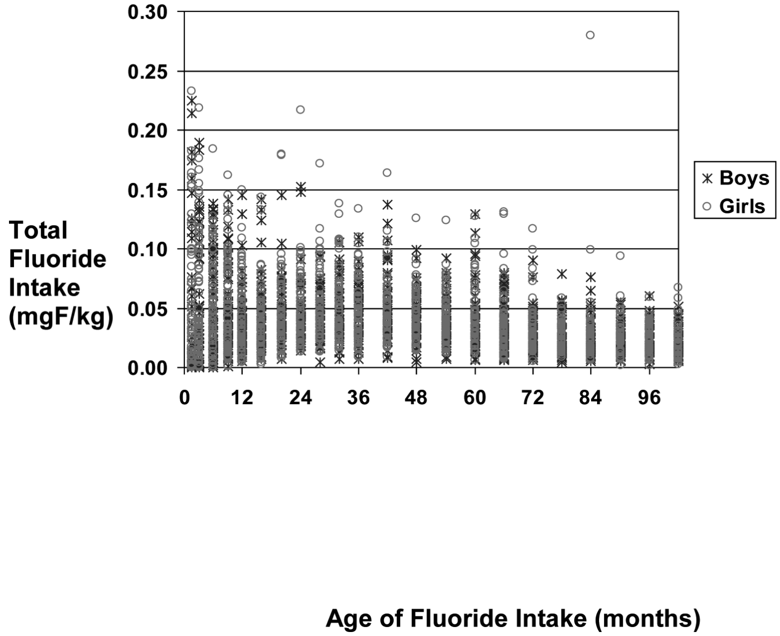

Figure 2.

Subjects with Neither Fluorosis nor Caries (n=153)