



# The average daily dose of fluoride: a model based on fluid consumption

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## Abstract

*The quantity of fluoride needed to prevent caries but avoid dental fluorosis is unknown. To estimate the desired daily dose of fluoride, we analyzed fluid consumption data from a stratified random sample of 7,345 children studied during the 1977–78 US Department of Agriculture Nationwide Food Consumption Survey and applied it to Dean's observations of optimally fluoridated communities in the 1940s. The average daily fluoride intake per kilogram body weight from optimally fluoridated tap water was highest (0.080 mg/kg/d) from 7 to 9 months of age, and declined linearly to 0.034 mg/kg/d at 12.5 to 13 years of age. The mean was  $0.068 \pm 0.008$  mg/kg/d from birth to age 7 years, and  $0.042 \pm 0.006$  mg/kg/d from age 7 to 13 years. The American Academy of Pediatrics supplementation schedule delivers fluoride dosage rates that are below our findings of the average daily dose of fluoride after the third month of life, although the two curves are within 0.006–0.013 mg/kg/d from 3 months to 16 years of age. While supplementation alone does not exceed the average daily dose of fluoride, the cumulative effects of fluoride from tap water, processed foods, ingested toothpaste, and dental treatments after the third birthday should be evaluated for their role in the increased prevalence of fluorosis. (Pediatr Dent 17:13–18, 1995)*

Fluoride from tap water is a major factor in the declining prevalence of dental caries in the United States.<sup>1</sup> For approximately 21 million children not served by a fluoridated water system,<sup>2,3</sup> systemic fluoride supplements are the preferred alternative. Current community fluoridation and fluoride supplementation policies are based on Dean's observations that a concentration of 1 ppm fluoride in community water yields the optimal balance between caries reduction and minimizing fluorosis.<sup>4</sup> However, 1 ppm is a concentration, not a delivered dose. To estimate the dose of fluoride from ingesting community water at 1 ppm, we must know the amount of water ingested. Regrettably, Dean did not report these data.

In the late 1980s, concern was raised over the increasing prevalence of enamel fluorosis. The manifestations of fluorosis range from barely noticeable opacities to severely pitted teeth. Most of these studies

identified prescribed fluoride supplements as the primary risk factor.<sup>2,5–12</sup>

In the 1930s and 40s, Dean identified a concentration of elemental fluoride in community water that balanced the risk of fluorosis with the benefit of caries prevention. That concentration, 1 ppm, has been adopted for decades as the optimal concentration for consumption. Dean's research is still the basis for community water supplementation programs. In the absence of sufficient natural fluoride exposure, intentional fluoride supplementation mimics the optimal community fluoride concentration Dean described.<sup>13–15</sup>

In the 1930s and 40s, the natural source of fluoride exposure was almost exclusively from drinking tap water. Unfortunately, Dean determined only a concentration — not a daily dose of elemental fluoride — that balanced risk and benefit. In Dean's era, with water the only major source of exposure, it was sufficient to describe a desirable concentration. But today fluoride sources are much more prevalent with fluoride present in toothpaste and the water in processed foods. Therefore, it is more important than ever to establish the average daily dose of fluoride.<sup>12–14</sup>

In 1958, the American Dental Association (ADA) recommended that children younger than 8 years old who lived in nonfluoridated areas receive fluoride supplementation. In 1975, a supplementation schedule was published, recommending daily fluoride doses of 0.25 mg from birth to age 2 years, 0.5 mg/d from age 2 to 3 years, and 1 mg from age 3 to 13 years.<sup>16</sup>

The current American Academy of Pediatrics (AAP) supplementation schedule differed only by continuing supplementation through age 16.<sup>17</sup> In response to concerns about the increasing prevalence of fluorosis, the ADA Council on Therapeutics recommended in April 1994 that fluoride supplementation not begin until age 6 months, and that daily doses of 0.25 mg be given until age 3 years, 0.50 mg from age 3 to 6 years, and 1.00 mg from age 6 to 16.<sup>18</sup> To date the AAP has not changed its recommendations.

Leverett<sup>14</sup> reported that estimates of optimal fluoride dosage rates in the literature ranged from 0.05 to 0.07 mg/kg/d and do not have a firm scientific basis. A working group sponsored by the National Institute of

Dental Research (NIDR) in April 1991 surmised that fluoride doses from ADA supplementation schedules result in dosage rates from 0.02 to 0.08 mg/kg/d between birth and age 13 years.<sup>19</sup> McClure<sup>20</sup> stated that 0.05–0.07 mg/kg/d was the optimal dosage rate for children from birth to age 12 years by estimating fluoride intake from the “average daily diet” in 1943. Another frequently cited value for optimal fluoride dosage rate, 0.06 mg/kg/d, was based on a “consensus of researchers worldwide.”<sup>21</sup> In the same year, the International Workshop on Fluorides and Dental Caries Reduction reported 0.05–0.07 mg/kg/d as the optimal dosage rate.<sup>22</sup>

A scientific method of determining the optimal fluoride dosage rate and evaluating existing and proposed supplementation schedules is to determine the tap water intake per kilogram of body weight for children from birth to age 13 years, assuming the tap water contains 1 ppm fluoride. The schedule that comes closest to the dosage rate that results from drinking Dean’s optimally fluoridated tap water would be best.

McClure,<sup>20</sup> Singer and Ophaug,<sup>23</sup> and Pang<sup>24</sup> estimated children’s daily water consumption at various ages but did not report body weight. In addition, their data were reported in multiyear strata. Fortunately, more detailed information on fluid consumption and individuals’ body weight has recently become available.<sup>25</sup>

We propose a criterion standard of optimal fluoride intake, which can be used as the basis for evaluating proposed changes in fluoride supplementation schedules. To define the average daily dose of fluoride (ADDF), we applied Dean’s optimal concentration to modern volume consumption data to determine fluid and fluoride intake. We explicitly assumed that total human fluid consumption in the 1940s is comparable to the volume of fluid consumed in modern times, although the fraction of this fluid that comes from community water may vary with time. Then we compared our estimate of optimal fluoride intake to the current supplement schedules.

## Methods

### Beverage consumption

To estimate the ADDF, we used age-specific fluid consumption data derived by Ershow and Cantor<sup>25</sup> from the 1977–78 Nationwide Food Consumption Survey (NFCS) of the US Department of Agriculture<sup>26</sup> to estimate how much community water the people in Dean’s study ingested. We explicitly assume that while dietary patterns may vary over time, total fluid consumption in the 1978 study is a valid estimator of fluid consumption in the 1930s and 40s. Using 114 strata based on three levels of stratification (geographic region, demographic or other geographic similarities, and level of urbanization), USDA researchers selected a probability sample of 14,930 private households in the contiguous 48 states and the District of Columbia. From

April 1977 through May 1978, people in approximately 3,750 households were interviewed each quarter. Occupants were asked to complete detailed three-day food and beverage diaries, specifying the number of 8-oz cups of water consumed and the body weight of each family member. Data were obtained from 30,770 individuals for all days of the week, with an overall participation rate of 68%. Ershow and Cantor point out that “it [is] unlikely that our estimates of water intake are affected by serious nonresponse bias. Our response rate of 68% is very similar to the 73% response rate obtained for NHANES [National Health and Nutrition Survey] II, and over 90% of all eligible individuals within the participating NFCS households agreed to participate in the individual intake surveys as well.”<sup>27</sup> In the standard fashion, weighting factors were applied to each observation to adjust for households that were selected but did not respond.<sup>26, 27</sup>

### Water consumption

Ershow and Cantor used food and beverage consumption data from the NFCS to establish total water and tap water consumption. They restricted the data to 26,446 individuals with a complete 3-day food and beverage record and known race, urbanization, weight, and education of heads of household. The study distinguished between two types of tap water: direct tap water, defined as plain water consumed as a beverage; and indirect tap water, defined as “tapwater used to prepare foods and beverages, such as tea or coffee.” Water added during commercial food preparation and the moisture content inherent in unprocessed foods, called intrinsic water, was not counted as tap water, but was included in estimates of total water intake.<sup>25</sup>

We analyzed publicly available data tapes derived from the Ershow and Cantor study, using only the data for the 7,345 children younger than 13 years of age. Since the data were obtained from a random, nationwide sample, and our objective was to estimate the ADDF for national policy purposes, we pooled fluid consumption data for all seasons, demographic clusters, and regions. This pooling yielded a sufficient number of subjects to permit analysis in narrow age bands. The 7,345 subjects of both sexes were divided into 3-month age groups from birth to 1 year, and into 6-month age groups from 1 to 13 years. For each stratum, we calculated the weighted means of all (direct plus indirect) tap water and intrinsic water consumed during the 3-day period and body weights using the means procedure from the Statistical Analysis System (SAS; Cary, NC). Breastfed infants were excluded from all analyses because of the difficulty in estimating their fluid intake.

To estimate the volume of fluid consumed as fluoride-containing tap water in Dean’s era, we summed the volume of tap water plus fluids in modern processed foods. Fluid in modern processed foods that would more likely have been consumed as tap water in

the 1940s included: soft drinks, juices, soups, fresh and canned fruits and vegetables. Fluid from cows' milk was excluded because it is low in fluoride. Fluid from infant formula was excluded because in the 1940s breast milk or cows' milk presumably would have been consumed. We referred to the sum of the volume of tap water plus modern fluids that would have been consumed as fluoride-containing tap water in Dean's era as Dean's water.

### Fluoride consumption

We defined ADDF as the volume of Dean's water multiplied by 1 mg fluoride per liter (1 ppm), calculating it for each age range. ADDF per kilogram was determined by dividing subjects' ADDF by their mean body weight. The mean ADDF was computed for each age stratum. Values were plotted at the midpoints of the age strata. For example, ADDF from birth to age 3 months was plotted at 1.5 months. Similarly, the ADA and AAP supplementation dose per kilogram was determined by dividing the recommended ADA and AAP doses by the mean body weight for each stratum.

Mean dosage rates were calculated for two age bands: birth to 7 years and 7 to 13 years, with the first band comprising the years of greatest vulnerability to fluorosis of the anterior teeth. Using this estimate as a baseline, we compared ADDF with the ADA supplementation schedule, to measure deviation from data we defined as the criterion standard.

### Results

Total fluid intake ranged from 944 ml/d from birth to 3 months of age to 1,955 ml/d in children 12.5 to 13 years of age. The Table shows stratum size, means, and standard deviations of daily intake of Dean's water, mean reported body weight computed from the Ershow and Cantor analysis of the USDA dataset, and estimated daily fluoride dosage rate based on intake of Dean's water. Dean's water intake ranges from 354 ml/d from birth to 3 months of age to 1,585 ml/d in children 12.5 to 13 years of age. Despite relatively large stratum sizes, there was substantial variation in all strata in tap water intake between subjects' 3-day average tap water intake, with coefficients of variation ranging from 38.1 to 76.8%. ADDF ranged from 0.080 mg/kg/d from 7 to 9 months of age to 0.034 mg/kg/d from 12.5 to 13 years of

TABLE. DAILY INTAKE OF DEAN'S WATER AND BODY WEIGHT FROM USDA NATIONWIDE SAMPLE OF 7,345 CHILDREN FROM BIRTH TO AGE 13\*

Age Group	N	Intake of Dean's Water (ml/d)		Mean Body Weight (kg)	Daily Dosage Rate of Fluoride (mg F/kg/d)
		Mean	SD		
birth-3 mos	98	354	266	4.96	0.071
4-6 mos	94	522	310	7.04	0.074
7-9 mos	119	710	308	8.85	0.080
10-12 mos	100	732	315	10.03	0.073
1-1.5 yrs	260	859	369	11.43	0.075
1.5-2 yrs	202	965	426	12.50	0.077
2-2.5 yrs	290	1000	396	13.92	0.072
2.5-3 yrs	269	1063	414	14.53	0.073
3-3.5 yrs	248	1108	449	15.73	0.070
3.5-4 yrs	259	1123	481	16.76	0.067
4-4.5 yrs	290	1173	458	17.69	0.066
4.5-5 yrs	283	1188	454	18.49	0.064
5-5.5 yrs	278	1177	418	19.67	0.060
5.5-6 yrs	265	1192	499	20.91	0.057
6-6.5 yrs	285	1201	478	22.31	0.054
6.5-7 yrs	290	1263	449	23.66	0.052
7-7.5 yrs	284	1327	482	25.46	0.052
7.5-8 yrs	333	1285	460	26.33	0.049
8-8.5 yrs	297	1356	484	28.69	0.047
8.5-9 yrs	269	1299	459	29.57	0.044
9-9.5 yrs	326	1334	456	31.36	0.043
9.5-10 yrs	287	1366	500	33.33	0.041
10-10.5 yrs	283	1349	495	35.49	0.038
10.5-11 yrs	309	1407	536	36.60	0.038
11-11.5 yrs	335	1462	544	39.73	0.037
11.5-12 yrs	311	1468	510	41.27	0.036
12-12.5 yrs	351	1531	580	44.20	0.035
12.5-13 yrs	335	1585	633	46.41	0.034

\* Dean's water includes tapwater, soft drinks, juices and soups.

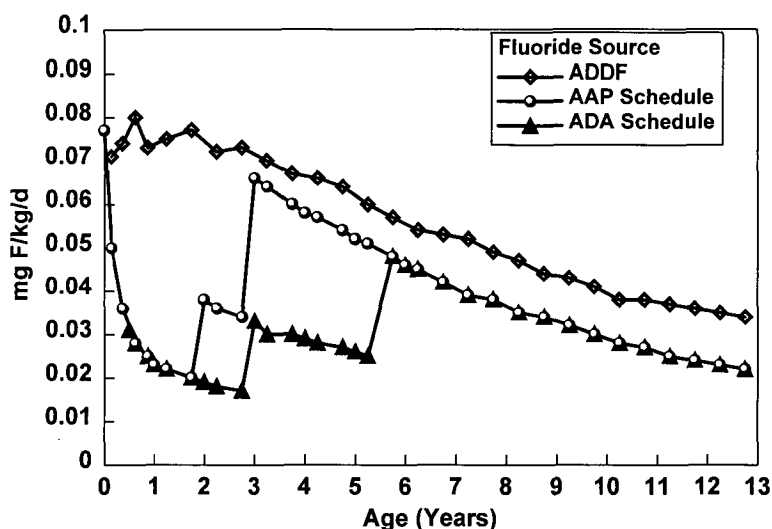


Figure. Average daily dose of fluoride (ADDF) and fluoride intake by body weight from the American Academy of Pediatrics (AAP) and American Dental Association (ADA) schedules from birth to 13 years of age. Note: Dean's water includes tap water, soft drinks, juices, and soups.

age. The mean fluoride rates ( $\pm 1$  SD) from birth to age 7 years and from 7 to 13 years were  $0.068 \pm 0.008$  mg/kg/d and  $0.042 \pm 0.006$  mg/kg/d, respectively.

### AAP supplementation schedule

The Figure presents the mean daily fluoride dosage rates from the AAP and ADA supplementation schedules and from our estimate of ADDF. Note that the dosage rate curve for the AAP supplementation schedule declines at birth, with inflection points at 2 and 3 years. This is due to the changes in supplementation dose from 0.25 to 0.50 to 1.00 mg/d (the numerator) and the changing rate of body weight increase (the denominator). Fluoride intake from the AAP supplementation schedule exceeds the ADDF from birth to age 3 months, after which it remains below the ADDF. The ADDF is greatest from 7 to 9 months of age, and declines linearly to 12.5 to 13 years of age. The difference between the lines begins to decrease at 2 years of age, when the recommended AAP fluoride dose increases from 0.25 to 0.5 mg/d, with another inflection point at 3 years of age when the recommended AAP dose increases to 1 mg/d. At this point, mean fluoride dosage rate from supplementation rises to 0.066 mg/kg/d, 0.006 mg/kg/d less than that of ADDF. From age 3 to 13 years of age, the mean fluoride dosage rate from supplementation declines linearly to 0.022 mg/kg/d. After age 3 years, the ADDF ranges from 0.006 to 0.013 mg/kg/d above the dosage rate from supplementation.

### ADA supplementation schedule

Supplementation begins at 6 months (0.25 mg/d) and is identical to the AAP schedule until age 2 years. From 2 to 3 years, daily dosage rate declines slowly to 0.017 mg/kg. As the recommended daily dosage rises to 0.50 mg, dosage rate rises to 0.33 mg/kg, declining steadily to 0.021 mg/kg before the sixth birthday. At 6 years of age daily dosage rises to 1.00 mg (0.046 mg/kg), at which point both curves become identical. Fluoride intake from the ADA supplementation schedule stays well below the ADDF.

### The ADDF

The ADDF is greatest from 7 to 9 months of age, and declines linearly to 12.5 to 13 years of age. The difference between the AADF and AAP schedule curve begins to decrease at 2 years of age, when the recommended ADA fluoride dose increases from 0.25 to 0.5 mg/d, with another inflection point at 3 years of age when the recommended AAP dose increases to 1 mg/d. At this point, mean fluoride dosage rate from supplementation rises to 0.066 mg/kg/d, 0.006 mg/kg/d less than that of ADDF. From age 3 to 13 years of age, the mean fluoride dosage rate from supplementation declines linearly to 0.022 mg/kg/d. After age 3 years, the ADDF ranges from 0.006 to 0.013 mg/kg/d above the dosage rate from supplementation.

## Discussion

Teeth are at greatest risk for fluorosis during calcification,<sup>29</sup> which occurs in the permanent anterior teeth (i.e., incisors and canines) between 4 months and 7 years of age — the period of greatest vulnerability to cosmetic fluorosis of these teeth.<sup>30</sup> Several reports suggest that the prevalence of fluorosis is increasing.<sup>2,5-12</sup> A 1986-87 national survey<sup>31</sup> concluded that 22.3% of children presented with some form of fluorosis, compared with 10% in an optimally fluoridated community described by Dean<sup>13,14</sup> more than 50 years earlier. A physiologically based fluoride dosage rate is critical to balance the risk of cosmetic fluorosis for calcifying anterior teeth against the benefit of caries protection.

The Figure shows that the ADDF is higher than the daily fluoride dosage rate from the AAP supplementation schedule. Assuming that the ADDF is a valid estimate of fluoride consumption in communities naturally fluoridated at 1 ppm, one would expect fluorosis prevalence to have declined (or at least remained constant), rather than to have increased substantially. This apparent paradox is resolved when one considers the effect of background fluoride. In Dean's time, tap water consumption was the only significant fluoride source. The AADF is the upper limit of fluoride intake. The AAP supplementation curve is a lower limit. Children taking fluoride supplements also are drinking ready-to-feed and concentrated formulas, reconstituted juices, and sodas, all of which may use fluoridated water. Since 56% of the population consumes fluoridated water, and 61% of public water systems are fluoridated,<sup>32</sup> one can easily see how much additional, or background fluoride children may be exposed to. The lower daily doses in the ADA supplementation recommendations respond to the problem of background fluoride. While the approach was empirical, we feel that its adoption will substantially reduce the future incidence of fluorosis as today's cohorts of infants and young children mature. This, however, does not diminish the need to develop a standard for daily fluoride intake.

Adding fluoride to community water supplies today is intended to replicate Dean's observations in the 1930s and 40s of the fluoride concentration naturally present in optimally fluoridated communities.<sup>13-15</sup> Likewise, current supplementation schedules are based on tap water consumption in the 1930s, when background fluoride intake was minimal. Decisions to prescribe fluoride supplements currently are based on the local fluoride concentration of tap water. Any contemporary schedule that fails to consider the increased background fluoride intake of the modern era is likely to predispose children to fluorosis. Our ADDF estimate accounts for the volume of contemporary fluid at a standard fluoride concentration (1 ppm). Fluoride intake from tap water, processed foods, ingested toothpaste, and dental treatments is the subject of our continued research.

The utility of our approach depends on the validity and generalizability of the USDA tap water consumption data and the reported weights of the subjects. While we cannot independently validate the tap water consumption results, selection bias is not a likely problem since the data were derived from a nationwide probability sample with a high response rate for a study of this magnitude. Reported body weights were very close to values from a standard growth table.<sup>33</sup> The data source has an additional strength in that the sample size is large for an analysis of this sort.

In deriving our fluid consumption estimate, we compensated for differences in dietary patterns between the 1930s and 1978. For example, in 1978 a substantial amount of fluid was obtained from commercially processed food (e.g., sodas, reconstituted juices, ready-to-feed and formula concentrates), which were rare, if not absent, in the communities Dean studied. To adjust for this, we counted all fluid obtained from processed beverages and infant formulas as tap water. We did not include the fluid volume of cows' milk because of its low fluoride content.

## Conclusions

We offer an estimate of the average daily dose of fluoride needed by children. This estimate is based on a scientifically valid survey of fluid consumption. We define the average dose needed by growing children in terms of body weight, rather than chronological age, to account for the expected variation in childhood growth and development. Anthropometrically based fluoride dosing offers the advantage of individualizing the risk-benefit equation for each child, on the basis of his or her own growth and development.

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## From The Archives

### Teething as a cause of fever, convulsions, and cerebral pathology

In the course of a few months (after birth) a new excitant of cerebral disorder presents itself in dentition (teething), which, according to Arbuthnot, we are to regard as the source of a tenth of the whole mortality of children.

Many writers have affirmed that the cutting of our teeth, being a natural process, should not generally be regarded as a source of danger to the young. Of this opinion were Drs. Cadogan and Armstrong.

But granting, for a moment, that, living according to the simple habitudes of nature, a child would pass through this trying period of its existence without either suffering or danger, does the acknowledgment affect the observed fact, that fevers, convulsions, and most especially, affections of the head, are daily arising from this particular disturbance? I apprehend not, and therefore class teething as an excitant of cerebral disorders in the young.

*Lancet*, 1834

## From The Archives

### Baby as a cause of maternal dental caries

It is believed that in those cases where child-bearing and nursing women fail to supply themselves with food containing the earthy elements, which are then especially needed, there is a drain upon their own organizations by which the child is, to some extent, at least, provided for at their expense. Their own teeth show the effects of starvation by an increased sensitiveness and rapid decay. A popular

apprehension of this fact has crystallized into the proverb, "For every child a tooth." During pregnancy and while nursing, more than usual attention should be given to the teeth, whose increased tendency to decay should be combatted by unremitting effort and watchfulness, in order that the future comfort and health of the mother may not be endangered or her personal attractions be lessened by the loss of teeth.

*in The Mouth and the Teeth*, James White, 1879