Water Consumption in the United States in 1994–96 and Implications for Water Fluoridation Policy

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Abstract

Objectives: *The purpose of this project was to describe current water consumption patterns and to compare them to findings from earlier studies. Current water consumption data also were used to reevaluate the association between water consumption and climate. These findings are of importance in estimating fluoride intake from fluoridated water.* ***Methods:*** *Findings from the 1994–96 Continuing Survey of Food Intakes by Individuals (CSFII) were compared to those from two earlier dietary studies, the 1977–78 Nationwide Food Consumption Survey (NFCS) and the pioneering research of Galagan and colleagues in the 1950s. Food consumption data were analyzed for 14,619 persons with food and beverage intake data for two 24-hour periods in the CSFII.* ***Results:*** *Increased consumption of infant formulas and decreased consumption of tap water and cow's milk were seen in the CSFII for infants compared to the NFCS. Older children and adults showed increased consumption of carbonated beverages and juices. While Galagan and colleagues found about a 60 percent increase in water consumption between the coldest (55°F) and warmest (85°F) conditions, only a 20 percent difference was seen between the winter and summer months in certain regions in the CSFII.* ***Conclusions:*** *No obvious strong or consistent association between water intake and month or season was apparent in these recent data. These findings are preliminary, and suggest that water fluoridation policy requires further research regarding water consumption and climate. [J Public Health Dent 1999;59(1):3-11]*

Key Words: diet, water consumption, climate, water fluoridation, fluoride, dental fluorosis.

In the United States about 135 million persons are on artificially fluoridated public water systems (1). The recommended levels for water fluoridation in the United States range from 0.7 to 1.2 ppm fluoride, depending on the mean maximum daily temperature for that area (2). This range is based on the presumption that water consumption increases with increasing climatic temperature.

Galagan and colleagues (3,4) observed that children residing in warmer communities developed more fluorosis than those living in colder climates exposed to similar concentrations of fluoride in the drinking water. Later studies by Galagan and others (5,6) measured the water consumption of children up to 10 years of age in two California cities at different seasons and proposed the following algebraic formula for describing the association between temperature and water consumption: water consumption (oz water/lb body weight)=–0.038+0.0062 mean daily maximum temperature (°F). Utilizing Dean's determination that 1.0 ppm F was optimal for caries prevention for children in the Chicago area (7,8), where the mean daily maximum temperature was 61.6°F, an equation for determining optimal water fluoridation levels for regions based on the temperature of a community was derived: ppm F=0.34 / (–0.038+0.0062 mean daily maximum temperature (°F)) (6).

Mean daily maximum temperatures in the United States range from approximately 50°F to 85°F. Based on Galagan and Vermillion's equation, recommended fluoridation levels range from 0.7 ppm F in the warmest regions (i.e., southern Texas and Florida) to 1.2 ppm F in the coldest regions (i.e., northern Minnesota and much of New England). These recommendations have been used by the US Public Health Service for public water fluoridation in this country since 1962 (2).

Since the time the early water consumption research was conducted, many technological and social changes have occurred that could affect water consumption patterns. In particular, there has been a widespread increase in the use of air conditioning, and there have been substantial changes in the beverage consumption habits of Americans, including changes in infant diets and the consumption of soft drinks.

This paper used data from a recent national survey of food consumption, the 1994–96 Continuing Survey of Food Intakes by Individuals (CSFII), commonly called "What We Eat in America," to describe current water consumption patterns. Findings from this survey were compared to those from two earlier dietary studies, the 1977–78 Nationwide Food Consumption Survey (NFCS) and the pioneering research in water consumption and climatic temperature of Galagan and colleagues in the 1950s. This paper compares water consumption data from three surveys to identify changes in water consumption patterns and to reevaluate the association between climatic temperature and water consumption.

Methods

The 1994-96 Continuing Survey of Food Intakes by Individuals. Our study is an analysis of data from the

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1994–96 Continuing Survey of Food Intakes by Individuals conducted by the US Department of Agriculture (9). These data and supporting documentation are available on CD-ROM from the National Technical Information Service. This study was a stratified, multistage area probability sample survey of individuals in US households. Stratification took into account geographic location, degree of urbanization, and socioeconomic characteristics. Interviews were conducted in the participants' dwellings and the participants were asked to report everything eaten or drunk the previous day between midnight and midnight. Proxy interviews by a competent individual in the household were conducted for children younger than 6 years of age and any other person who was not able to report for themselves due to physical or mental limitations. It was intended that each participant would provide two separate 24-hour diet recalls, with three to 10 days between the interviews. Some persons, however, were not available for the second interview. For analysis in this paper, only persons who completed both interviews were included.

Over the three years of the survey, the first-day response rate was 80.0 percent and the response rate for persons completing both days of the dietary survey was 76.1 percent, with 15,303 persons completing both 24-hour diet summaries. From this group, 14,640 persons had complete water, food, demographic, and body weight data. Twenty-one persons with a total water intake relative to body weight over 6 standard deviations from the mean (greater than 249 g water/kg/day) were eliminated as outliers, leaving a total of 14,619 participants.

A computer-assisted food coding and data management system was used by the USDA to calculate the nutritional composition of the food consumed. This software used a database of 7,352 food descriptions and recipes to provide measures of nutritional factors such as protein, fats, carbohydrates, fiber, vitamins, minerals, and water content. Of particular interest for this analysis were the measures of tap water consumed and the amount of water present in the food and beverages consumed.

The sample size, weighted population size, and mean body weights in five age groups are shown in Table 1. These age groups were used in the analyses of the NFCS, so we also used them in our analysis to permit comparisons of the two surveys.

TABLE 1
Sample Sizes and Mean Body Weight (kg) of Persons by Age Groups in 1977–78 NFCS (10) and 1994–96 CSFII (9)

	1977–78 NFCS			1994–96 CSFII		
Age Group	*n**	*N* (x 1000)†	Mean Body wt (kg)	*n**	*N* (x 1000)†	Mean Body wt (kg)
<1 years	403	2,174	7.7	296	3,152	7.8
1–10 yrs	5,605	34,271	23.1	3,644	36,773	22.9
11–19 yrs	5,801	36,810	55.2	1,587	32,623	59.8
20–64 yrs	11,732	11,7443	70.5	6,983	149,751	76.4
65+ yrs	541	22,340	68.6	2,109	30,204	72.5
All	15,523	213,038	59.3	14,619	252,503	59.8

*Sample size.
†Weighted population size.

TABLE 2
States Included in Regions in 1994–96 CSFII (9)

Region	States
Northeast	Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Midwest	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin
South	Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia
West	Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming

TABLE 3
Sample Size by Month and Region, Children 0–10 Years of Age, 1994–96 CSFII (9)

Month	Northeast	Midwest	South	West	Total
Jan	49	63	71	71	254
Feb	56	93	149	73	371
Mar	44	68	127	58	297
Apr	69	74	113	58	314
May	86	124	155	88	453
Jun	53	99	107	53	312
Jul	60	68	147	82	357
Aug	71	104	163	101	439
Sep	52	43	74	50	219
Oct	81	92	136	94	403
Nov	69	88	133	80	370
Dec	30	44	45	32	151
Total	720	960	1,420	840	3,940

Food and Beverage Sources of Consumption. This current analysis of the sources of water consumption in

TABLE 4
Sample Size by Month and Region, All Persons, 1994–96 CSFII (9)

Month	Northeast	Midwest	South	West	Total
Jan	164	187	292	228	871
Feb	269	337	530	270	1,406
Mar	156	239	417	197	1,009
Apr	233	238	418	243	1,132
May	280	395	538	313	1,526
Jun	190	361	403	212	1,166
Jul	242	267	579	322	1,410
Aug	273	428	597	334	1,632
Sep	199	216	336	203	954
Oct	330	398	571	359	1,658
Nov	230	343	483	343	1,399
Dec	67	141	147	101	456
Total	2,633	3,550	5,311	3,125	14,619

the CSFII parallels that done previously with the NFCS by Ershow and Cantor (10) to allow observations of changes in water consumption patterns between the two surveys. Eight general sources of water consumption were considered in the NFCS analyses, these were: (1) drinking water; (2) milk and milk drinks; (3) infant formula; (4) coffee, tea, and similar beverages; (5) baby food; (6) carbonated beverages; (7) fruit and vegetable juices and other noncarbonated drinks; and (8) other foods and beverages.

The findings from the CSFII survey were compared to results previously published from the 1977–78 NFCS study (10), the original survey also conducted by the US Department of Agriculture. The sampling, survey, and analytical methodologies of these two surveys were similar, so that comparisons of findings are appropriate. While the CSFII used two separate 24-hour diet recalls, the NFCS used one 24-hour diet recall and a separate two-day diet record.

Water Consumption in Different Months and Seasons. The 1994–96 CSFII included data on the person's region of residence and the dates of the two interviews. The states included in each region are listed in Table 2. The survey took place throughout the year and approximately equal proportions of the sample in each region were interviewed during each season (Tables 3 and 4). For these analyses, the month of the first interview was used to determine the individual's interview month.

In addition to comparisons with the 1977–78 NFCS survey, findings from the 1994–96 CSFII survey were compared to the Galagan studies (5,6). The Galagan research was done in a very different manner from either the NFCS or CSFII surveys. Galagan's research obtained five-day diet information from 455 children up to the age of 10 in two California cities. Water consumption measurements included water from: (1) drinking water; (2) infant formula preparations or reconstituted milk made with tap water; (3) juices diluted with tap water; (4) soups diluted with tap water; and (5) tap water-based beverages, such as tea or coffee. Fortunately, the CSFII food definitions are quite specific and make distinctions between reconstituted beverages made with tap water (such as frozen concentrated orange juice) and beverages that are "ready-to-eat" and have not had home tap water added. It was possible, therefore, to select food and beverage items in the CSFII data that closely matched the water measured in the Galagan research. Note that in these analyses the total quantity of the fluid (i.e., milk, juice, soup), not the specific amount of water in the food or beverage, was used. While Galagan did, in fact, measure other fluid intake such as that from prepared juices and soft drinks, these sources of water were not included in their temperature analyses.

Galagan and colleagues used meteorologic data obtained at the children's town to assess the association between mean daily maximum temperature and water consumption. No temperature measures were included in the CSFII and only the region, not the exact residence of a respondent, was reported. Therefore, it is not possible to directly obtain an actual temperature measure for each person in the CSFII. In light of these limitations, we used the month and season of interview as a proxy for temperature, assuming a general temperature cycle, with the winter months being the coldest and the summer months being the warmest.

Statistical Methods. The comparisons of the results of the CSFII survey to both the NFCS and Galagan et al. data are necessarily qualitative in nature. No statistical tests were done for these comparisons. The SAS System for Personal Computer version 6.12 (11) was used for descriptive statistics and data file management of the 1994-96 CSFII data. Sample weighting factors were used in all analyses of the CSFII data to allow the data to represent the population of the United States at the time of the survey. SUDAAN was used to calculate standard errors adjusted for the complex sampling design; the "With Replacement" sampling design was used for these calculations (12).

Results

Food and Beverage Sources of Water Consumption. Figures 1–5 present the mean amount of water consumed from eight sources of water in foods and beverages by age categories. Overall water intake decreased from 163 grams per kg of body weight per day (g/kg/d) to 130 g/kg/d between the two surveys for infants younger than 1 year old. For infants under age 1 (Figure 1), there has been a substantial change in dietary patterns, with decreased consumption of water from drinking water and cow's milk and an almost equivalent increase in the amount of water consumed with infant formula. In the CSFII, 66 percent of the water consumed by infants came from formula that included ready-to-feed, reconstituted powdered, and reconstituted concentrated liquid forms. Of the 86 g/kg/d of water from formula, about 68 g/kg/d came from powdered reconstituted formula. This estimate is a conservative one because some reported formula consumption did not have its

specific form (ready-to-feed, powder, or concentrated liquid) described.

For persons aged 1–10 (Figure 2) and 11–19 years (Figure 3), there is an evident trend for increased consumption of water from carbonated drinks and juices with a concomitant decrease in the amount of water ingested from drinking water, milk, and coffee and tea. In the 1–10-year-old children, the proportion of total water coming from drinking water declined from 32 percent to 24 percent between the two surveys. Note that while water consumption relative to body weight declines with increasing age in the 0, 1–10-, and 11–19-year age groups, total consumption of water increases with age.

Persons aged 20–64 years (Figure 4) showed an increase in water consumption from carbonated beverages and juices, but also a slight increase in their consumption of drinking water. Decreased consumption of water was seen from milk and coffee and tea. The proportion of total water from drinking water was similar, at about 30 percent, for the two surveys for this age group.

In the oldest age group (Figure 5), persons over age 64, water consumption patterns are remarkably similar for the two surveys. There is, however, a slight increase in carbonated drinks and juice consumption and a decrease in the water obtained from milk and coffee and tea.

The standard errors for the CSFII data in Figures 1–5 are generally small in comparison to the mean values. This observation indicates that the data are fairly precise population estimates.

Water Consumption at Different Months and Seasons. Water consumption was defined by Galagan et al. (5) as the amount of drinking water, formula, soups, and home-prepared beverages consumed per day per pound of body weight. The researchers then plotted the consumption of water against the mean maximum daily temperature. The results, converted into g/kg/d units, along with the best-fit regression line and its equation, are shown in Figure 6. Galagan et al. found approximately a 60 percent increase in total water consumption from 55°F (20.2 g/kg/d) to 85°F (32.0 g/kg/d).

Water intake was determined for 3,940 children 10 years of age and younger in the CSFII using similar definitions for water consumption as those of Galagan et al. (5). The composition of this group by region and month of examination is shown in Table 3. The data were stratified by region because it was apparent that there were important regional differences in water consumption. Examinations were fairly evenly distributed in the different regions and months, except that slightly fewer children were surveyed during December.

The amount of water consumed per

FIGURE 1
Sources and Quantities (g water/kg body weight/day) of Consumed Water, Children up to 1 Year, 1977–78 NFCS (10) and 1994–96 CSFII (9) (Error bars indicate standard error of the mean)

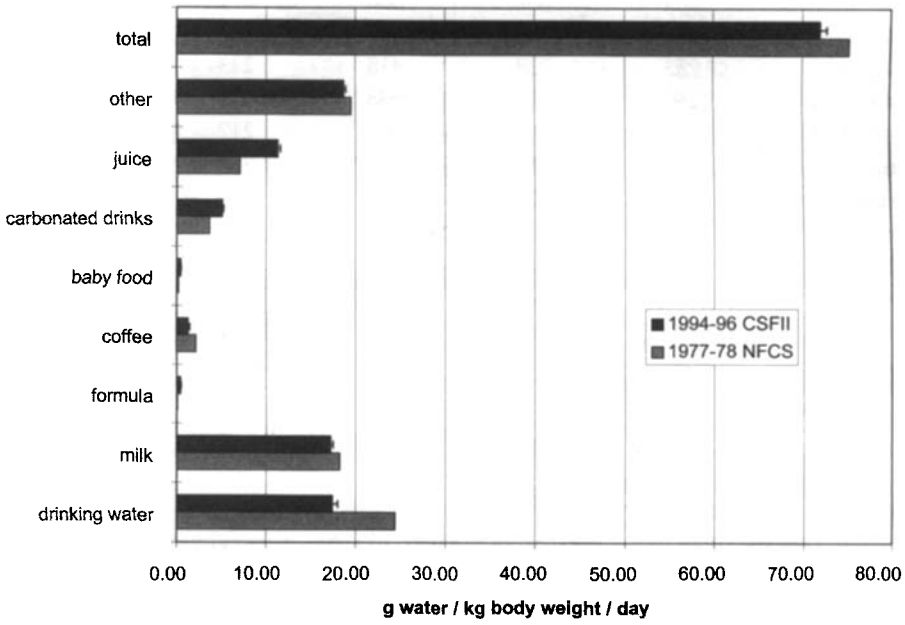


FIGURE 2
Sources and Quantities (g water/kg body weight/day) of Consumed Water, Children Aged 1–10 Years, 1977–78 NFCS (10) and 1994–96 CSFII (9) (Error bars indicate standard error of the mean)

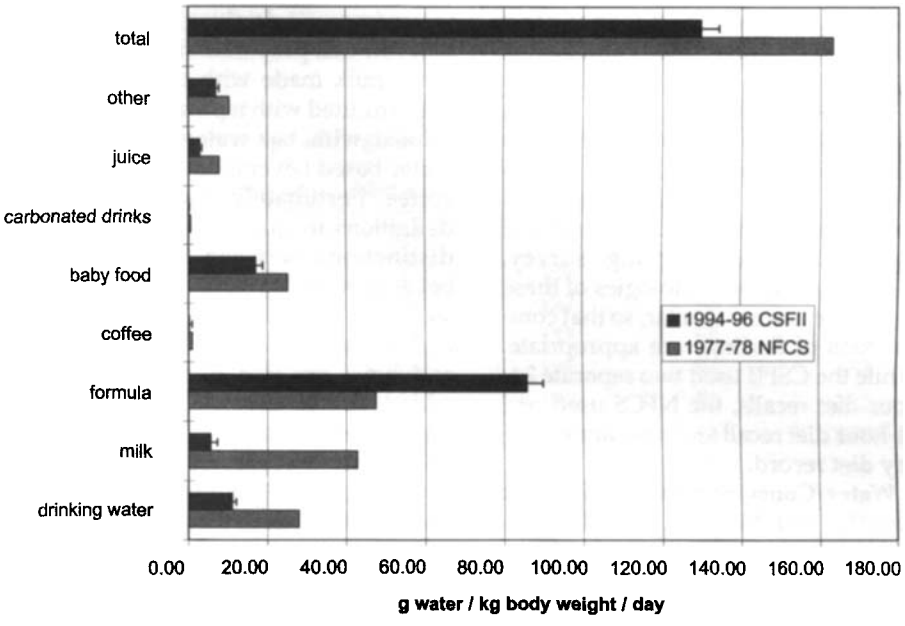


FIGURE 3
Sources and Quantities (g water/kg body weight/day) of Consumed Water, Persons Aged 11–19 Years, 1977–78 NFCS (10) and 1994–96 CSFII (9)
(Error bars indicate standard error of the mean)

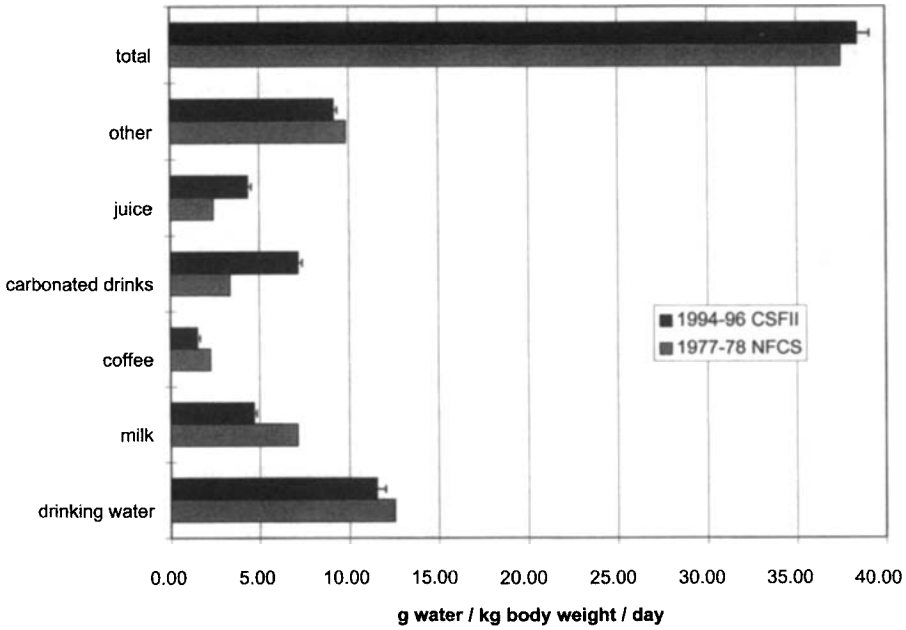
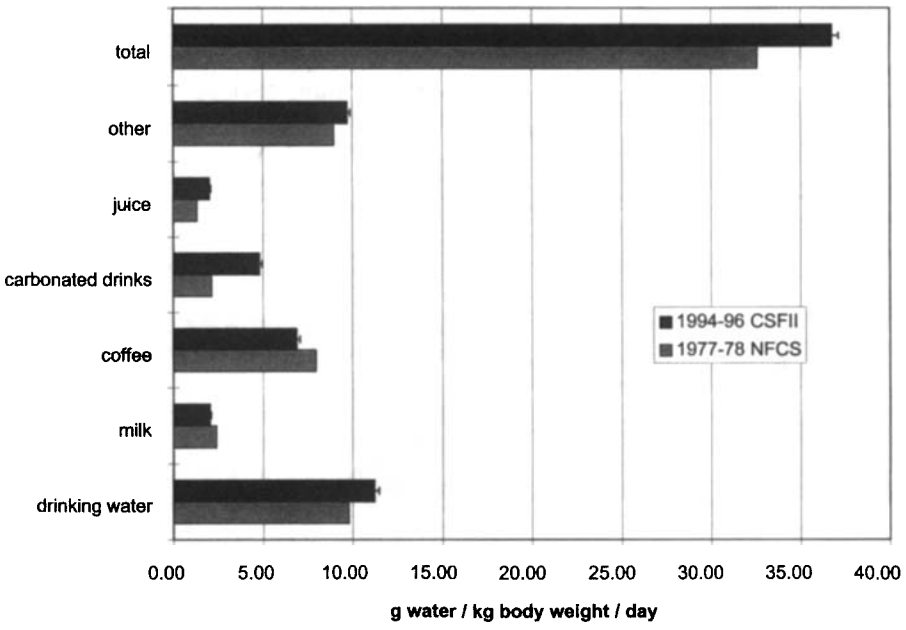


FIGURE 4
Sources and Quantities (g water/kg body weight/day) of Consumed Water, Persons Aged 20–64 Years, 1977–78 NFCS (10) and 1994–96 CSFII (9)
(Error bars indicate standard error of the mean)



child per day, using the same five categories as Galagan et al. (5), was determined and is shown by month and region in Figure 7 and by season and region in Figure 8. Overall, the Northeast, Midwest, and Southern regions do not differ greatly in water consumption levels throughout the year, with total consumption generally in the 20–30 g/kg/d range. The Western region, however, demonstrates markedly higher water consumption than the other regions for almost all months and shows large monthly fluctuations.

A great deal of variation is seen in Figure 7 for water consumption from month to month for each of the regions, with little trend apparent. In Figure 8 water consumption data for children 10 years old and younger are presented by season rather than months. Seasons are defined in the same manner as for the 1977–78 NFCS analyses: winter includes January–March, spring includes April–June, summer includes July–September, and fall includes September–November. Only in the Southern region is any trend seen for increasing water consumption from the winter to summer months, with a 20 percent increase in the south from winter (24.0 g/kg/d) to summer (28.7 g/kg/d). Rather large standard errors are seen for each grouping, indicating a fairly high amount of variation of water consumption among the data.

Similar analyses were done for all 14,619 persons in the CSFII data. A fairly even distribution of participants by region and month was obtained in the survey, as seen in Table 4. Again, fewer persons were surveyed during December. As with the children, the Western region had overall higher water consumption than the other regions, and no strong pattern of association between month and water consumption was evident (Figure 9). These characteristics also are shown in Figure 10, which graphs water consumption by season and region. Only in the West is a trend seen for increasing water consumption from the cooler to warmer seasons. In this region the summer consumption (25.5 g/kg/d) is 20 percent greater than the winter consumption (21.3 g/kg/d).

Figure 11 shows the g of tap water per kg body weight per day consumption by season for different age groups from the Ershow analysis of the NFCS data (10). Ershow's definition of "tap water" includes direct tap water (drinking water) and indirect tap water (tap water in food and beverages), and is fairly similar to the definition of total water consumption used by Galagan and used in the CSFII analyses above. Note that the NFCS tap water definition included tap water that was included in all foods and beverages consumed; thus these values of water consumption are slightly higher than that for the Galagan and CSFII analyses. Differences between the summer and winter

FIGURE 5
Sources and Quantities (g water/kg body weight/day) of Consumed Water, Persons Older than 64 Years, 1977–78 NFCS (10) and 1994–96 CSFII (9) (Error bars indicate standard error of the mean)

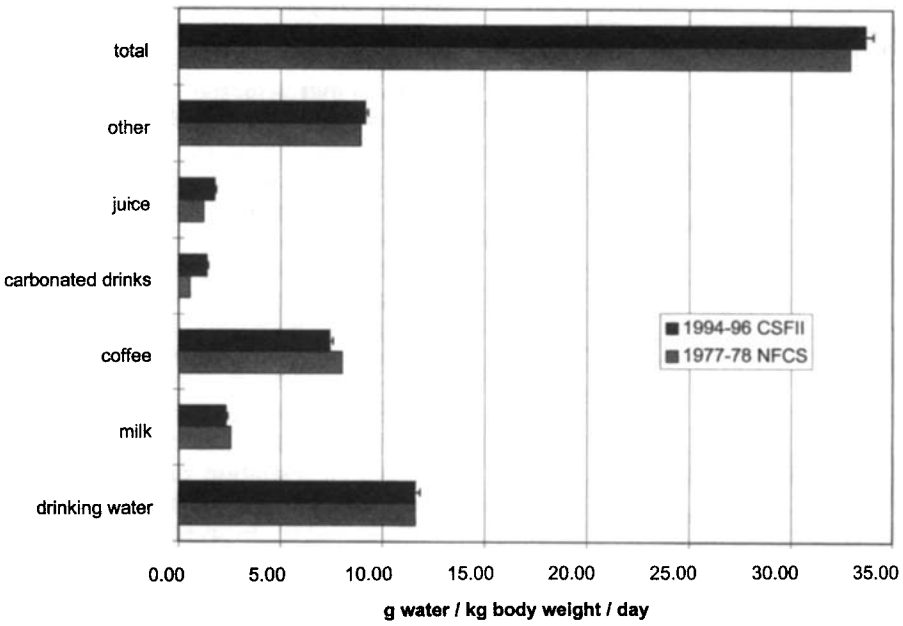
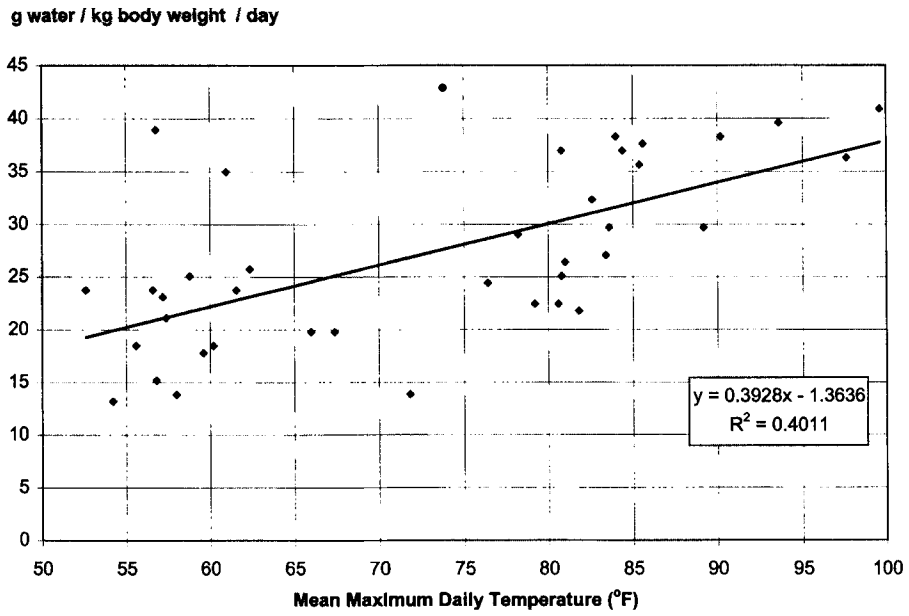


FIGURE 6
Mean Maximum Annual Temperature (°F) and Water Consumption (g water/kg body weight/day) as Determined by Galagan et al. (5)



months varied from 7 percent for the age 20–64 group, to 22 percent for the younger than age 1 group.

Discussion

This paper has made comparisons of findings from three separately conducted diet surveys. This type of analysis is limited by differences in the study protocols and analytical methodologies. One limitation of the 24-hour recall, used in the CSFII and the NFCS, is that the reported day's diet may not be representative of the person's typical diet. This technique therefore is considered to be fairly unreliable for describing an individual's dietary intake, but is considered valid for describing the dietary intake of a group in epidemiologic studies. Also, some inaccuracy is likely when a caregiver is reporting for a child. For very young children, caregivers are usually well aware of their child's diets—but this may be less so with older children. We would expect some underreporting of food consumption for these older children whose caregivers may not be aware of food consumed outside of the home.

Water consumption can be measured in many ways, particularly with regard to the water content in foods and beverages. In this paper we used similar definitions of "water intake" when comparing the different surveys. To avoid problems due to the changes in body weight over time, water consumption was measured relative to body weight. While it would have been ideal if temperature information was available for the CSFII participants, we were limited to using the month of examination as a proxy for temperature. Because of the nature of the data, statistical tests between the three studies are not presented in this paper. We felt that the simple descriptive presentation of results was appropriate and sufficient for indicating obvious and clear patterns and trends.

Figures 1-5 show changes in the sources of consumed water between the 1970s and 1990s. Infants now consume more formula and less drinking water and cow's milk than they did in the 1970s NFCS study. The decreased consumption of cow's milk is in accord with current nutritional recommendations for infants (13). The implication for dentistry is that we should be aware of these sources of water in determining fluoride intake for infants. Because most of the water from infant formula is added at the home, we must consider the fluoride content of the tap water when assessing fluoride intake.

From the CSFII data as previously discussed, a typical infant up to age 1 year would consume about 11 g/kg/d of water from drinking tap water directly, and 68 g/kg/d of water from tap water used in reconstituted powdered formulas (Figure 1). If this water was fluoridated at 1 ppm F, the infant would ingest approximately 0.079 mg

FIGURE 7
Water Consumption (g water/kg body weight/day) by Month and Region, Children Aged 10 years and Younger, 1994–96 CSFII (9)

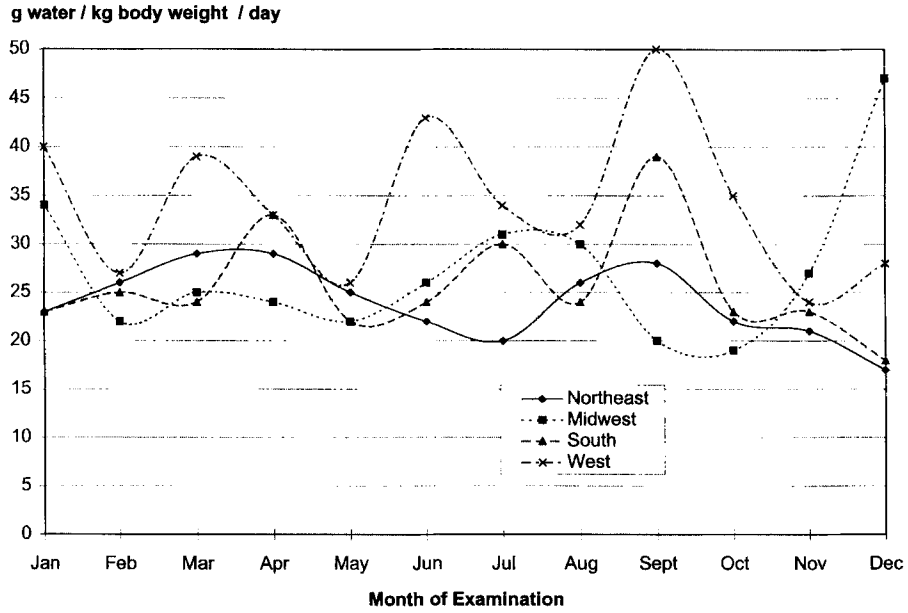
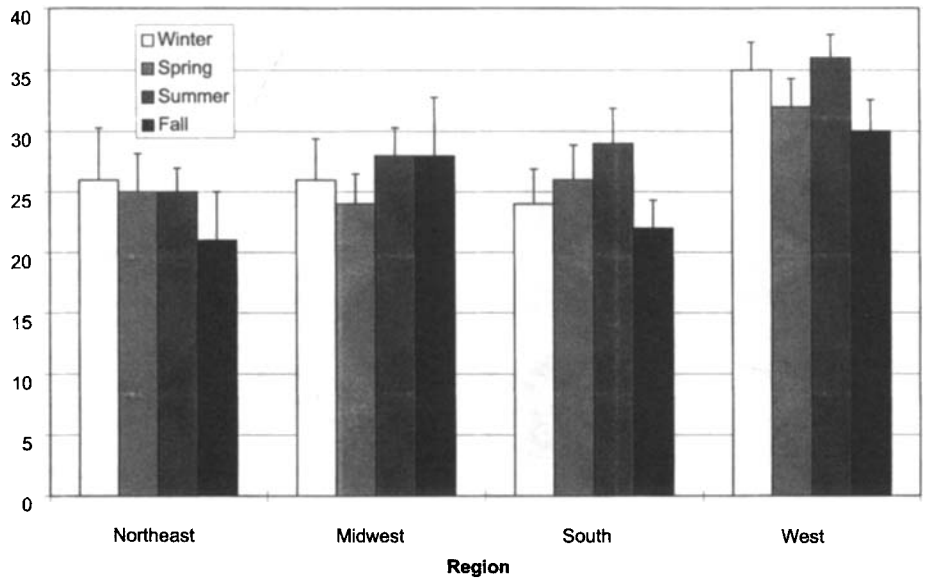


FIGURE 8
Water Consumption (g water/kg body weight/day) by Season and Region, Children Aged 10 years and Younger, 1994–96 CSFII (9)
(Error bars indicate standard error of the mean)



F/kg/d. This amount is greater than the generally estimated "optimal" range of 0.05–0.07 mg/kg/d, though there is no firm scientific basis for this estimated range (14-17). Using the 1978–79 NFCS data, Shulman et al. (18) determined that fluoride intake for children consuming 1 ppm F water was approximately 0.07 to 0.08 mg F/kg/d for children up to 1 year of age. Levy et al. (19) estimated that children drinking 1 ppm fluoridated water and reconstituted powdered formula would consume 0.20, 0.18, and 0.08 mg F/kg/d at 6 weeks, 6 months, and 1 year of age, respectively. Because of the timing of enamel development, fluoride intake by children in the early years of life is of great importance with regard to fluorosis development (20-23). The changes observed in the water consumption patterns of infants may be a factor in the increased prevalence of fluorosis observed in recent years (24-27).

For older children and adults, carbonated drink and juice consumption have about doubled between the NFCS and the CSFII. The increase in consumption of these beverages has been reported previously (28,29) and is not unexpected. The dental community is, of course, concerned with excessive consumption of these drinks because of their potential cariogenicity (28). However, these beverages also may be a notable source of fluoride. The source of the water used in preparation of these beverages can vary greatly; therefore, it is difficult to determine the precise amounts of fluoride ingested from these beverages. Persons in nonfluoridated areas will consume some foods and beverages processed with fluoridated water—the so-called "halo effect" of fluoride benefits—just as persons in fluoridated areas will consume foods and beverages processed with nonfluoridated water. These sources of fluoride must be considered in estimating total fluoride ingestion (17,30).

Our current water fluoridation standards regarding temperature are based solely on Galagan's 1957 work. It is apparent from the analyses of more recent data that water ingestion does not vary with temperature as much as it appeared to do in Galagan's time. In the 1994–96 data, it appears that the regional differences are greater than the monthly or seasonal differences, with the Western region having notably higher water consumption. A similar pattern was observed in the 1977–78 NFCS data (10). In the CSFII, an increase of about 20 percent was seen in water consumption between the winter and summer months in the South for children aged 10 years and younger, and a similar increase was seen for all age groups in the West. This 20 percent difference is similar to that seen in the NFCS data between summer and winter water consumption. In contrast, Galagan's studies demonstrated about a 60 percent difference in water consumption between the coldest and warmest time

FIGURE 9
Water Consumption (g water/kg body weight/day) by Month and Region, All Persons, 1994–96 CSFII (9)

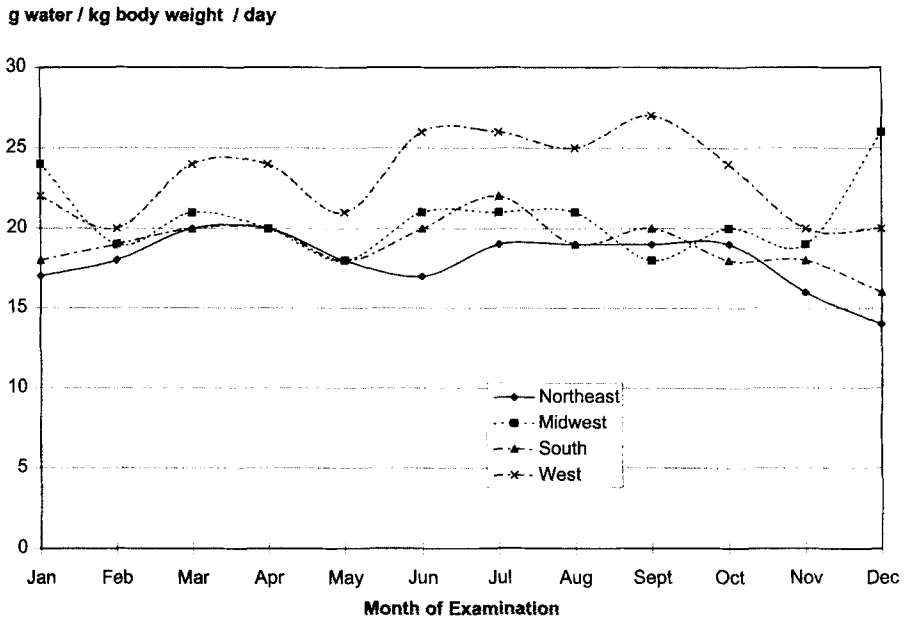
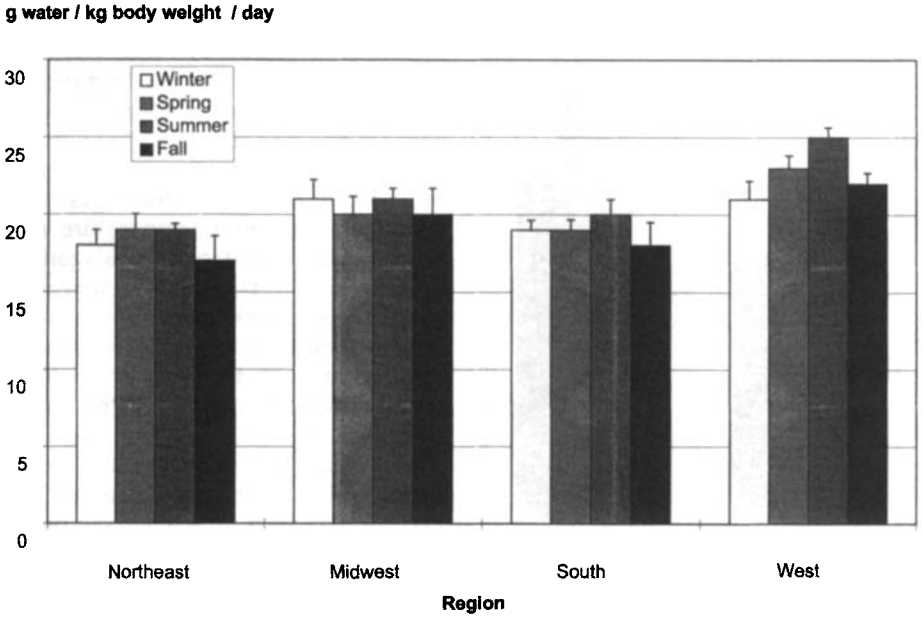


FIGURE 10
Water Consumption (g water/kg body weight/day) by Season and Region, All Persons, 1994–96 CSFII (9) (Error bars indicate standard error of the mean)



periods (5).

This analysis of the sources and quantities of water consumption is pertinent to the ongoing discussions of caries and fluorosis trends in both fluoridated and nonfluoridated communities. While a substantial decline in caries prevalence in the United States since the start of water fluoridation is apparent (31-34), the prevalence of dental fluorosis also has increased during this time (24-27). An understanding of current water consumption is vital to understanding the role water fluoridation has played in caries and fluorosis trends.

The lack of any obvious strong or consistent variation in water consumption with different months and seasons in these modern water consumption studies leads us to question the need for recommending different water fluoridation levels according to mean maximum temperature, and warrants a more thorough investigation. Ideally, a longitudinal study of persons throughout the year with accurate food intake, climatic, and behavioral data should be done to identify the determinants of water consumption and to better quantify levels of ingested fluoride.

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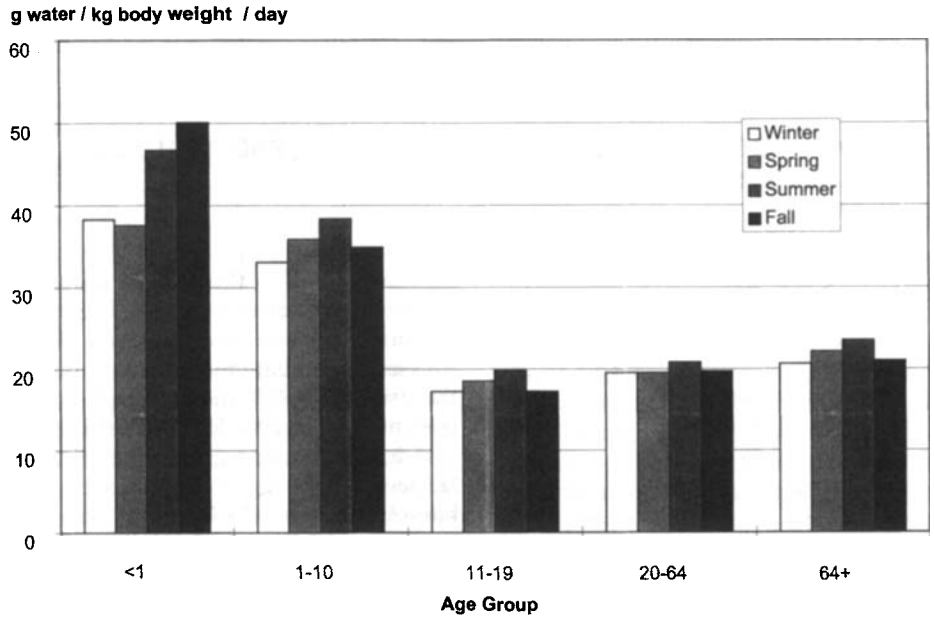
FIGURE 11
Water Consumption (g water/kg body weight/day) by Season and Age Group, 1977–78 NFCS (10)



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