Sources of Dietary Fluoride Intake in 6-7-Year-Old English Children Receiving Optimally, Sub-optimally, and Non-fluoridated water

Fatemeh V Zohouri, BSc, MSc, PhD, RPHNutr; Anne Maguire, BDS, FDS (RCS Edin), PhD; Paula J Moynihan, BSc, SRD, PhD, RPHNutr

Abstract

Objectives: *Due to increased consumption of pre-packaged drinks, tap water may no longer be the principal source of water intake and consequently fluoride intake. Little is known about the importance of solid foods as fluoride sources and how the relative contribution of foods/drinks to fluoride intake is affected by residing in fluoridated or non-fluoridated areas. This study investigated the relative contributions of different dietary sources to dietary fluoride intake and compared this in children residing in optimally artificially fluoridated, sub-optimally artificially fluoridated, and non-fluoridated areas.* ***Methods:*** *Thirty-three healthy children aged 6 years were recruited from fluoridated and non-fluoridated communities and categorised into three groups based on fluoride content of home tap water: optimally fluoridated (≤0.7 mgF/L), sub-optimally fluoridated (≥0.3 to ≤0.7 mgF/L) and non-fluoridated (≤0.3 mgF/L) drinking water. A 3-day dietary diary collected dietary information. Samples of foods/drinks consumed were collected and analyzed for fluoride content.* ***Results:*** *Drinks provided 59%, 55% and 32% of dietary fluoride intake in optimally, sub-optimally and non-fluoridated areas respectively. Tap water, fruit squashes and cordials (extremely sweet non-alcoholic fruit flavoured drink concentrates) prepared with tap water, as well as cooked rice, pasta and vegetables were important sources of fluoride in optimally and sub-optimally fluoridated areas. Carbonated soft drinks and bread were the most important contributors to dietary fluoride intake in the non-fluoridated area.* ***Conclusion:*** *The main contributory sources to dietary fluoride differ between fluoridated and non-fluoridated areas. Estimating total fluoride intake from levels of fluoride in tap water alone is unlikely to provide a reliable quantitative measure of intake. Studies monitoring dietary fluoride exposure should consider intake from all foods and drinks.*

Key Words: Fluoride, diet, children, source of fluoride, water, soft drinks

Introduction

An adequate, regular intake of fluoride is accepted as having a protective effect against dental caries (1, 2); however, the overexposure of children to systemic fluoride can affect tooth development. Excessive intake of systemic fluoride up to the age of 3 increases the risk of dental fluorosis of the aesthetically important permanent incisors as well as the first permanent molars, while excessive fluoride intake from 3 to 6 years can put the later developing permanent canines, premolars and second molars at risk of dental fluorosis (1). For this reason the WHO has recommended that levels of fluoride exposure be monitored regularly (3, 4), especially in children and before introducing any community-based fluoridation or individually-based fluoride supplementation program.

The sources of ingested fluoride include fluoridated water, fluoride supplements and foods and drinks prepared with water or which contain fluoride naturally, as well as inadvertent ingestion of fluoride contained in toothpastes and other oral health products. However, diet including water can contribute up to 70% of total daily fluoride intake in children up to age 6 (1). Therefore, determining and monitoring the contribution of fluoride from the diet to total fluoride exposure, is important.

Fluoride intake from water, consumed either directly, or indirectly by adding water to beverages and food, has been estimated in several studies (1, 5-9). However, few studies (10, 11) have investigated the relative contributions of all dietary components towards total fluoride exposure. These studies found drinking water as the main source of fluoride for children residing in optimally (≥0.7 mgF/L) and sub-optimally (0.3-0.6 mgF/L) fluoridated areas. However, the only study that reported the contribution of different dietary sources to fluoride intake in an industrialized country (11) was conducted over 20 years ago and was based on collection of a 2-week food supply for an average child (termed as market basket) rather than the actual, individual food consumption. Due to recent trends towards drinking more bottled water, moves towards a greater consumption of drinks/foods made outside the home (12) and the fact that foods/drinks sold in a fluoridated area may have been manufactured in a non-fluoridated area or vice versa, the fluoride concentration of the home water supply may no longer be a reliable index of dietary fluoride exposure. To confirm if this is the case, current and reliable information on major dietary sources of fluoride in the modern day diet of children and the impact of the fluoride content of water on total di-

Send correspondence and reprint requests to: Dr A. Maguire, School of Dental Sciences, Newcastle University, Framlington Place, Newcastle upon Tyne, NE2 4BW, UK. E-mail address: a.maguire@ncl.ac.uk. All authors are affiliated with the School of Dental Sciences, Newcastle University. **Source of support**: The Borrow Foundation. Manuscript received 4/11/06; accepted for publication 7/24/06.

etary fluoride intake is needed. Therefore, the aim of this study was to investigate the relative contributions of different dietary sources to dietary fluoride intake and to compare this in children, aged 6 years, residing in fluoridated and non-fluoridated areas.

Materials and Methods

Subjects. Ethical approval was obtained from the Local Research Ethics Committees in the study areas. Schools were identified by contacting the Education Authorities in the North East of England. Using a cluster random sampling technique with schools as the sampling unit, four schools from non-fluoridated areas and two schools from fluoridated areas were selected. Healthy children aged 6 years, of both genders, with no metabolic disorder who had resided lifelong in the region were identified through the selected schools. An information leaflet containing detailed study information was enclosed with a letter to parents of the children, and the nature of the study was verbally described to children and parents who expressed an interest in the study. Informed written consent was obtained from the parents of the children who agreed to take part in the study.

In total, 33 healthy children were recruited; 18 from schools in the fluoridated area and 15 from schools in the non-fluoridated areas. To confirm the fluoride content of each child's home tap water supply, three samples of home tap water from each individual's home were analyzed using a fluoride-ion-selective electrode after addition of TISABII and a direct method of fluoride analysis (13). The subjects were then categorised into three groups based on the fluoride content of their home tap water supply: those receiving optimally fluoridated ($\geq$0.7 mgF/L), sub-optimally fluoridated ($\geq$0.3 to <0.7 mgF/L) and non-fluoridated (<0.3 mgF/L) drinking water.

Anthropometric measurements. Children were visited at home by a nutritionist and anthropometric measurements were taken. Heights of the children were measured to the nearest cm, in socks but without shoes, and weight was measured to the nearest 0.1 kg without shoes and heavy clothing. Body Mass Index [BMI= Weight(kg)/Height(m^2)] was calculated for each child.

Dietary assessment. Dietary information was collected using a food diary completed over 3 consecutive days (two weekdays and one weekend day) followed by a private interview on the fourth day by a nutritionist. For this purpose, a diary was given to each parent with instructions for its completion, stressing the importance of recording all foods and drinks consumed over the 3-day period. The study was also explained thoroughly to each child and they were encouraged to cooperate with their parents in recording (or drawing) foods and drinks consumed. Information recorded included: description of the food or drink, the amount consumed described using household measures, time of consumption and recipes of home-prepared foods/drinks. In order to determine portion size, a food portion atlas (14) was used. In addition, the volumes/weights of glasses, cups and bowls etc. used by subjects were measured (by a measuring cylinder/portable electronic balance) immediately after the interview. Food diaries were coded using an electronic version of the current UK food composition tables (15) and entered into a purpose-designed MS Access database. Queries were run to generate reports for the following outcome variables: anthropometric and food diary data (average daily intake of energy, macronutrients and fluoride intake).

The validity of the dietary information was estimated by calculating the mean energy intake (MJ) of children and comparing this with the Estimated Average Requirements (EAR) (16) and corresponding data reported for British children in the UK National Diet and Nutrition Survey (NDNS) (17). In addition, the predicted Basal Metabolic Rate (BMR) was calculated using the Schofield equations (18) and was used to estimate the Physical Activity Level (the ratio of estimated energy intake to predicted BMR) of each child. The PAL was then compared with the reference range for this age group (19).

Collection and analysis of food and drink samples. Samples of home tap water were collected from each child's home. Samples of food and drink consumed by the children during the 3-day dietary assessment period were collected. Samples of home-made food/drink were obtained and manufactured food/drinks were purchased from local shops as appropriate. Samples of school meals were obtained from schools where relevant.

The fluoride contents of waters and non-milk based drink samples were measured directly using a fluoride-ion-selective electrode after addition of TISABII (14). Food and milk-based drink samples were analyzed using the modified silicon-facilitated diffusion method (20-22).

Since no data for fluoride content were available in any food composition table, data for the determined amount of fluoride contained in food and drink samples (μg/100g of food/drink) was added to all consumed food/drink items listed in the electronic version of the food composition tables using the purpose-designed MS Access database programmed for this study. The program was designed to allow the inclusion of values for the fluoride contents of certain food items that required water in their preparation and cooking, separately, for each of the three groups, according to the F content of their home water supply.

In order to determine the relative importance of different foods/food groups to dietary fluoride, all the food and drinks were categorized into subgroups (Table 1). The percentage contribution of these food groups to total dietary fluoride intake was determined.

Data analysis. Descriptive data analysis was carried out using SPSS to derive the mean (sd) of daily dietary fluoride intake, and percentage contributions of different groups of drinks and foods to total dietary fluoride intake in the three areas studied based on the fluoride concentration of the home water supply. The study was

Table 1
Foods and drinks categories for dietary fluoride analysis

Drinks	Foods
(i) tap drinking water	(i) fruit and raw vegetables
(ii) bottled drinking water (carbonated/non-carbonated)	(ii) soup and gravy prepared by adding tap water
(iii) infusion of black and herbal tea prepared from tap water and tea	(iii) bread purchased from shops
(iv) coffee prepared with tap water	(iv) rice, pasta, vegetables boiled with tap water
(v) hot-chocolate prepared by adding boiled tap water to chocolate powder	(v) fish and seafood
(vi) milk	(vi) breakfast cereals without milk
(vii) squash and cordials (extremely sweet non-alcoholic fruit flavoured drink concentrates) prepared by adding tap water	(vii) meat and meat products
(viii) non-carbonated soft drinks such as ready- to-drink fruit juice	(viii) confectionery, cakes and sweets including chocolate confectionery
(ix) carbonated soft drinks including sparkling juice drinks.	(ix) other foods such as dairy products, butter and oil, sauces etc

Table 2
Mean (sd) age, anthropometric parameters, daily intake of energy and macronutrients for children receiving optimally, sub-optimally and non-fluoridated home water supplies

	OF water* n=6	SF water† n=9	NF water‡ n=18	All subjects n=33
Age (y)	6.9 (0.7)	6.6 (0.4)	6.9 (0.4)	6.9 (0.7)
Height (cm)	116 (5)	118 (6)	122 (6)	119.8 (5.7)
Weight (kg)	21.9 (1.1)	22.3 (3.5)	25.0 (5.1)	23.7 (4.4)
BMI¶ (kg/m^2)	16.4 (1.9)	15.9 (2.1)	16.7 (2.7)	16.4 (2.4)
Energy (MJ)	6.7 (0.9)	6.4 (1.5)	7.5 (1.3)	7.0 (1.3)
Fat (g)	65.1 (11.1)	62.2 (21.9)	73.1 (13.1)	68.7 (16.0)
Carbohydrate (g)	213.0 (35.0)	198.0 (35.2)	236.3 (51.5)	221.6 (46.9)
Protein (g)	52.5 (7.9)	52.1 (15.0)	58.2 (11.9)	55.5 (12.2)

* Optimally fluoridated water (≥0.7 mgF/L in water)
† Sub-optimally fluoridated water (≥0.3 - <0.7 mgF/L in water)
‡ Non-fluoridated water (<0.3 mgF/L in water)
¶ Body Mass Index

not specifically designed to make a gender comparison, therefore mean values were reported for all variables by group except for the energy intake data which were used to compare results with reference values to determine the validity of food diaries. A Pearson correlation coefficient was used to report the trends in the relationship between fluoride concentration of home supply water and total dietary fluoride intake and dietary fluoride intake from drinks and foods separately.

Results

Thirty-three children were recruited into the study (16 boys and 17 girls) and all completed the 3-day food diary and anthropometric assessments.

According to the fluoride content of the children's home tap water supply, 18 children received non-fluoridated water (0.08±0.03 mgF/L), 9 received sub-optimally fluoridated water (0.47±0.09 mgF/L), and 6 children received optimally fluoridated water (0.82±0.13 mgF/L).

The mean (sd) age, height, weight and BMI for all children was 6.9 (0.7) yr, 119.8 (5.7) cm, 23.7 (4.4) kg, and 16.4 (2.4) kg/m^2, respectively. The mean (sd) energy intake was 7.0 (1.5) MJ for boys and 7.1 (1.2) MJ for girls. The mean (sd) PAL was 1.6 (0.4) for the boys and 1.8 (0.3) for girls. The mean daily intakes of fat, carbohydrate and protein for all children were 68.7 (16.0), 221.6 (46.9) and 55.5 (12.2) g, respectively with little variation in energy and macronutrient intakes between groups (Table 2).

The mean total daily dietary fluoride intakes of children according to the fluoride content of their home water supply are presented in Table 3. The mean (sd) total daily dietary fluoride intake for children receiving optimally-fluoridated water was 0.591 (0.280) mg/day, while for those children receiving sub-optimally-fluoridated water it was 0.349 (0.108) mg/day, and for those receiving non-fluoridated water it was 0.188 (0.088) mg/day. The mean daily dietary fluoride intake expressed on a body weight basis was 0.027 mg/kgbw/day in children receiving an optimally-fluoridated home water supply, 0.016 mg/kgbw/day in children receiving sub-optimally-fluoridated water, and 0.008 mg/kgbw/day receiving a non-fluoridated water supply.

For children receiving optimally-, sub-optimally- and non-fluoridated water, the absolute intakes of fluoride from drinks were 0.382 (0.193) mg/day, 0.210 (0.134) mg/day and 0.062 (0.069) mg/day respectively.

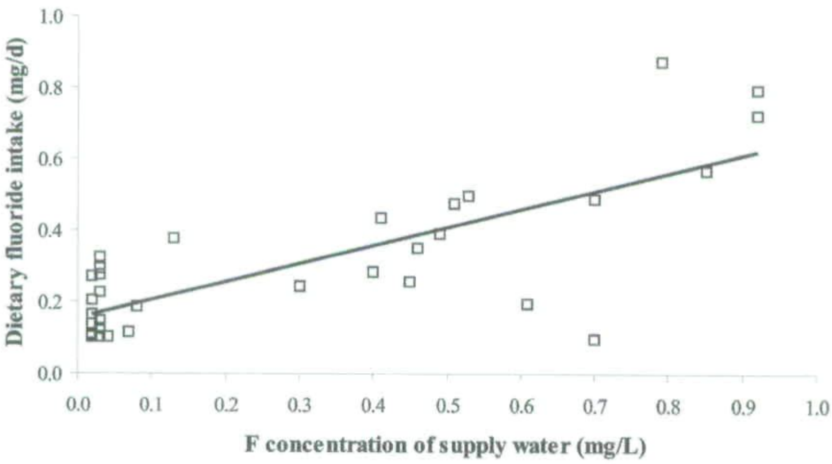
The percentage contribution of various food group sources to total dietary fluoride intake are presented according to fluoride content of home water supply in Table 4. The percentage contribution of all drinks to total daily dietary fluoride intake was 59%, 55% and 32% for children receiving optimally-, sub-optimally- and non-fluoridated water respectively. Squash and cordials (extremely sweet non-alcoholic fruit flavoured drink concentrates), prepared by adding tap water, contributed 31%, 21% and 7% of the total daily dietary fluoride intake in children receiving optimally,

Table 3
Mean (sd) dietary fluoride intake (µg/day) from various sources of drinks and foods for children receiving optimally, sub-optimally and non-fluoridated water

	OF water* n=6	SF water† n=9	NF water‡ n=18
All drinks (µg/day)	382 (193)	210 (134)	62 (69)
Bottled water	< 1 (<1)	< 1 (<1)	< 1 (<1)
Tap water	83 (10)	81 (72)	7 (8)
Tea	29 (70)	0¶	9 (29)
Coffee	20 (50)	2 (5)	0¶
Hot- chocolate	< 1	15 (33)	2 (5)
Milk	3 (2)	2 (1)	2 (2)
Squash and cordials (extremely sweet non-alcoholic fruit flavoured drink concentrates) prepared by adding tap water	214 (221)	95 (122)	10 (6)
Non-carbonated soft drinks	4 (8)	4 (5)	8 (15)
Carbonated soft drinks	28 (32)	12 (12)	23 (33)
All foods (µg/day)	209 (128)	139 (44)	126 (78)
Fruit and raw vegetables	15 (15)	19 (28)	16 (21)
Soup and gravy	2 (3)	<1 (1)	<1 (<1)
Bread	12 (11)	20 (17)	20 (14)
Rice, pasta, boiled vegetables	117 (119)	54 (49)	16 (21)
Fish & sea-foods	< 1 (<1)	2 (3)	7 (28)
Breakfast cereals	2 (1)	5 (11)	6 (8)
Meat and meat products	5 (3)	6 (4)	17 (21)
Confectionery, cakes and sweets	11 (5)	10 (9)	15 (9)
Others	45 (20)	22 (23)	28 (25)
Total dietary intake (µg/day)	591 (280)	349 (108)	188 (88)

* Optimally-fluoridated water (≥0.7 mgF/L in water)
† Sub-optimally-fluoridated water (≥0.3 - <0.7 mgF/L in water)
‡ Non-fluoridated water (<0.3 mgF/L in water)
¶ Not consumed

Figure 1
Relationship between fluoride concentration of home water supply (mg/L) and total dietary fluoride intake (mg/d): Pearson Correlation Coefficient = +0.78, p<0.001



sub-optimally and non fluoridated water respectively. In contrast, due to differences in the source of drinks consumed, children living in sub-optimally fluoridated homes received 24% of their daily fluoride intake from tap water alone while those in optimally-fluoridated and low fluoride homes received 11% and 4% of their total daily fluoride intake from tap water alone respectively. Furthermore, the contribution of tea, recognized as a good source of fluoride, to total dietary fluoride intake was low. Only one child in the optimally-fluoridated and two children in non-fluoridated areas consumed tea and overall it represented only 3% of total dietary fluoride intake for children in these areas.

With regard to fluoride intake from foods, the food group requiring water in their preparation and cooking, 'rice, pasta and boiled vegetables' contributed the largest proportion of fluoride in optimally and sub-optimally fluoridated areas and accounted for 16% and 17% of total daily fluoride intake respectively. In contrast, in the non-fluoridated area, 'bread', which can contain up to 40% water, was the largest source of fluoride, contributing 12% of intake, followed equally by 'rice, pasta and boiled vegetables' (9%), 'meat and meat products' which can contain bone, (9%) and 'confectionery, cakes and sweets' (9%).

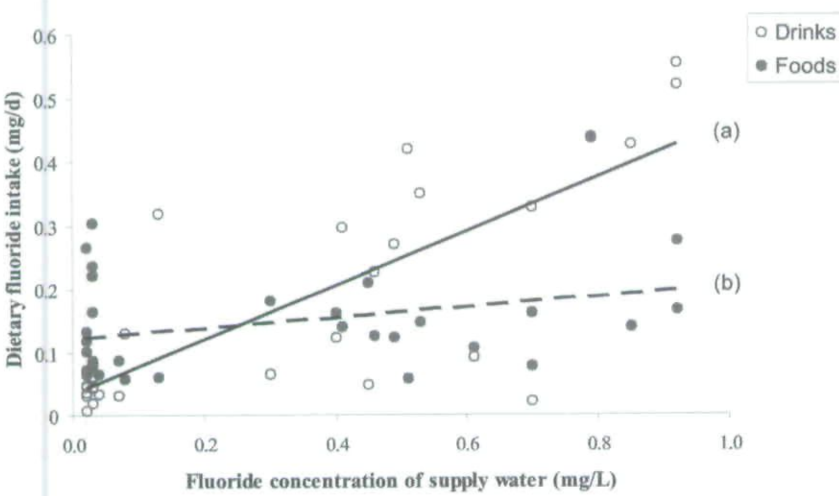
There was a significant positive correlation between the fluoride concentration of home tap water and total dietary fluoride intake (Pearson correlation coefficient = +0.78, P<0.001) (Figure 1). The two outliers receiving water fluoridated at 0.6 and 0.7mgF/L, but with low dietary F intake were children who did not drink tap water or squash made with tap water. In addition, a strong positive correlation between the fluoride concentration of home tap water and fluoride intake from drinks was found (Pearson correlation coefficient = +0.81, P<0.001) (Figure 2). In contrast, the correlation between fluoride concentration of home tap water and fluoride intake from foods was not statis-

Table 4
Mean (sd) percentage contribution of different food groups to total daily dietary fluoride intake for children receiving optimally, sub-optimally and non-fluoridated water

	OF water* n=6	SF water† n=9	NF water‡ n=18
All drinks(%)	59 (20)	55 (23)	32 (20)
Bottled water	< 1 (<1)	<1 (<1)	< 1 (<1)
Tap water	11 (12)	24 (18)	4 (5)
Tea	3 (8)	0¶	3 (10)
Coffee	4 (10)	<1 (2)	0¶
Hot- chocolate	<1 (1)	4 (10)	1 (4)
Milk	1 (2)	<1 (<1)	1 (1)
Squash and cordials (extremely sweet non-alcoholic fruit flavoured drink concentrates) prepared by adding tap water	31 (30)	21 (25)	7 (5)
Non-carbonated soft drinks	2 (3)	1 (1)	4 (6)
Carbonated soft drinks	6 (6)	4 (4)	11 (10)
All foods (%)	41 (20)	45 (23)	67 (20)
Fruit and raw vegetables	2 (2)	8 (12)	7 (7)
Soup and gravy	<1 (<1)	<1 (<1)	<1 (3)
Bread	5 (7)	6 (7)	12 (8)
Rice, pasta, boiled vegetables	16 (13)	17 (18)	9 (11)
Fish & sea-foods	<1 (1)	< 1 (1)	2 (9)
Breakfast cereals	1 (1)	1 (3)	3 (4)
Meat and meat products	2 (3)	2 (2)	9 (8)
Confectionery, cakes and sweets	2 (2)	3 (2)	9 (8)
Others	12 (13)	6 (7)	15 (9)

* Optimally-fluoridated water (≥0.7 mgF/L in water)
† Sub-optimally-fluoridated water (≥0.3 - <0.7 mgF/L in water)
‡ Non-fluoridated water (<0.3 mgF/L in water)
¶ Not consumed

Figure 2
Relationship between fluoride concentration of home water supply (mg/L) and intake of fluoride from (a) drinks (mg/d): Pearson Correlation Coefficient = +0.81, p<0.001, and (b) foods (mg/d): Pearson Correlation Coefficient = +0.31, p=0.08



tically significant (Pearson correlation coefficient = +0.31, P=0.08) (Figure 2(b)).

Discussion

This paper provides, for the first time, comprehensive descriptive information on dietary sources of fluoride intake in English children aged 6 years receiving optimally-, sub-optimally-, and non-fluoridated water in their domestic tap water. However, in view of the relatively small numbers of children studied, in common with most previous fluoride intake and excretion studies carried out in young children, some caution is necessary in the interpretation of the results.

In this study, a 3-day food diary with interview along with collection of food/drink samples was used, a method which allowed more detailed qualitative and quantitative information to be recorded, such as source of fluoride; data which may not be collectable using other methods such as the duplicate plate technique in which all food samples are pooled. These other methods such as 'market-basket' collection, self-reported drink consumption, and food frequency questionnaires which have been used in some studies are also less likely to provide an accurate quantitative measure of dietary intake of fluoride and its sources (23).

Validation of dietary intake was estimated by comparing energy intake of the children studied with Estimated Average Requirement (EAR) (15) and national data, and also by calculating PAL; the ratio of Energy Intake to BMR. These are suitable and simple checks on the validity of group estimates of energy intake (19, 23). The energy intake of boys in the present study, at 7.0 MJ was slightly lower than the EAR of 7.2 MJ for boys aged 4-6 years (15), but higher than the value of 6.4 MJ for British boys reported in the National Diet and Nutrition Survey (16). The mean energy intake for girls (7.1 MJ) was higher than the EAR of 6.5 MJ and the value of 5.9 MJ reported for British girls aged 4-6 years. The mean PALs for boys and girls in the present study were higher than the mean PALs of 1.39 and 1.48 reported for 3-8 year old males and females with healthy BMIs (24), respectively, but were similar to the PAL of 1.6 reported for children aged 5-9 from industrialized countries (25). These validations indicated that collection of dietary data was likely to be satisfactory in this study.

The study was undertaken in three groups of children receiving drinking water containing low, sub-optimal or optimal levels of fluoride to provide information on effect of fluoride concentration of supply water on total dietary fluoride intake and the contribution of different foods/food groups to fluoride intake in these groups. Children in non-fluoridated areas consumed almost three times less mgF/day from their total diet compared with the children receiving optimally fluoridated water, while the amount of dietary fluoride (µg/day) contributed by drinks was six times higher for children receiving optimally-fluoridated water compared with those receiving a low fluoride home tap water supply.

The mean dietary fluoride intake of 0.008 mg/kg bw/day obtained for the children receiving non-fluoridated water, was similar to the mean dietary intakes of 0.008 mg/kg bw/day estimated for 3-4 and 7-8 year old children resident in non-fluoridated areas of New Zealand, and of 0.007 mg/kg bw/day for 11 children aged 16 to 40 months from a non-fluoridated area of Puerto Rico (26), although lower than the value of 0.018 mg/kg bw/day reported for 7 Japanese children aged 5 and 6 years old residing in a non-fluoridated area (27), 0.023 mg/kg/bw for 32 Iranian children aged 4 years living in a non-fluoridated area (28), and 0.014 mg/kg bw/day for 14 American children aged 16 to 40 months (26).

For the children receiving optimally fluoridated water, the mean dietary fluoride intake of 0.027 mg/kg bw/day found in the present study, was higher than the value of 0.019 mg/kg bw/day reported for both 3 to 4 year old New Zealand (29) and 16 to 40 month old American children (26) living in fluoridated areas (1.0 mgF/L) and that reported for 11 German children aged 3 to 6 (just two children were 6 years old) living in a non-fluoridated area but receiving fluoridated salt (0.011 mg/kg bw/day) (30). However, the children in the present study were receiving a daily fluoride intake lower than the 0.055 mg/kg bw/day reported for Mexican children aged 15 to 36 months residing in a non-fluoridated community but receiving fluoridated salt (31).

With regard to sub-optimal fluoridation, a mean dietary intake of 0.047 mg/kg bw/day has been estimated for 3 to 5 year old Chilean children residing in a community with a fluoride concentration of 0.5 to 0.6 mg/L (32), which is higher than the 0.016 mg/kgbw/day obtained for the children receiving sub-optimally fluoridated water (0.5 mgF/L), in the present study.

The proportional contribution of all drinks to total daily dietary fluoride intake was similar in optimally and sub-optimally fluoridated groups at 59% and 55% respectively, although for children receiving non-fluoridated water, drinks contributed only 32% of the total daily fluoride intake. Widely differing data have been reported for contribution of all drinks to daily dietary fluoride intake: 18% for 15 to 36 month old Mexican (31) and 71% for 1 to 6 year old German children living in non-fluoridated areas but receiving fluoridated salt (30); 73% for American children aged 16 to 40 months receiving fluoridated water (26); 54% for Chilean children aged 3 to 5 years (32) and 79% for Iranian children aged 4 year ; and 47% and 66% for 16 to 40 month old children living in non-fluoridated areas of Puerto Rico and Indiana, respectively. Crosby and Shepherd (1957) reported the volume of water consumed in summer to be more than twice that in winter; also Zohouri and Rugg-Gunn (10) have reported that dietary fluoride intake was 35 to 54% higher in summer than in winter. The differences in the contribution of fluoride ingested from all drinks, reported between studies, may be due to the effect of temperature on fluid consumption, differences in dietary culture, as well as differences in the diet analysis methods which were often inadequate to accurately quantify fluoride intake. Children consuming locally produced drinks and drinks made up using home water supplies are more likely to receive a fluoride intake from drinks which reflects local water fluoride levels, compared with those children receiving prepackaged manufactured drinks which will reflect the fluoride conditions in the area of manufacture.

While there are several reports on the dietary sources of fluoride of infants and toddlers, there are few data on the sources of dietary fluoride of young children. The present study indicated that tap water alone, as a drink, was not the predominant source of fluoride intake for 6-year-old English children. The contribution of drinking water to total dietary fluoride intake ranged from 4% in the non-fluoridated area to 24% in the sub-optimally-fluoridated area which is lower than those data reported for North American children aged 6 months – 2 years: 14%, 46% and 54% in communities with non-, sub-optimally and optimally fluoridated water (11), respectively. Zohouri and Rugg-Gunn (10) reported that drinking water provided 36% and 38% of dietary fluoride for 4-year-old Iranian children living in non- and sub-optimally-fluoridated areas, respectively. Schamschula *et al.* (33) found that 9% and 21% of the total daily dietary fluoride of Hungarian children aged 3 to 4 years, came from drinking water in areas where the concentration of fluoride in the water supply ranged from 0.06 to 0.11 mg/L and 0.5 to 1.1 mg/L, respectively.

For all drinks consumed, squash/cordials (extremely sweet non-alcoholic fruit flavored drink concentrates) prepared by adding tap water, were the main sources of fluoride intake for English children living in optimally and sub-optimally fluoridated areas while for children residing in the non-fluoridated area, carbonated soft drinks were the main source of fluoride from drinks.

Except for the studies of Ophaug *et al.* (1985) of North American infants and toddlers aged 6 months – 2 years, and Zohouri and Rugg-Gunn on 4-year-old Iranian children (10), no other study has identified the contribution of different food groups to dietary fluoride intake in children. Although the 'fish and seafood' group is generally recognized as a relatively good source of fluoride intake (34), in this study less than 1% of total dietary fluoride intake came from this food group. In contrast, the study of Ophaug (11) the percentage of the dietary fluoride intake contributed by 'meat , fish , poultry' group ranged from 7.1% for the US toddlers residing in non-fluoridated areas to 17.1% for those residing in fluoridated areas. The effect of water-borne fluoride on the fluoride content of cooked 'rice, pasta, vegetables' was found to be substantial in the present study. This group of foods, which were prepared and boiled/cooked with tap water, was the main contributor to dietary fluoride intake in optimally- and sub-optimally-fluoridated areas. In contrast, in the non-fluoridated area, the 'bread' group made an important contribution to the children's total dietary fluoride intake. Tea can contribute substantially to total dietary fluoride intake among tea consumers in both fluoridated and non-fluoridated areas since the fluoride content of tea is considerably high (34). In the present study, however, the mean percentage contribution of tea to total dietary fluoride intake was low because only 3 children consumed tea. Since iron absorption is reduced by tea consumption, it should not be promoted as a source of fluoride (35).

In conclusion, this study showed that foods can make a substantial proportional contribution to total dietary fluoride intake, particularly among children residing in non-fluoridated areas. The main contributory sources of dietary fluoride differed between fluoridated and non-fluoridated areas. The concentration of fluoride in home supply water still impacts upon dietary fluoride intake in young children. However, estimating total fluoride intake from levels of fluoride in tap water alone is unlikely to provide a reliable quantitative measure of intake and it is important that fluoride intake from all foods and drinks should be considered when monitoring fluoride exposure. There is a need for further research in this area to include larger scale fluoride intake and excretion studies for all age groups to determine differences in sources of fluoride exposure between age groups and between individuals with different socio-economic status.

Acknowledgement

The authors wish to thank Miss J. Hatts for her help with recruiting the subjects and collecting the samples and Mr. P.N. Hindmarch and Miss E.A. Earl for their help with the fluoride analysis. The authors would also like to acknowledge the children and their parents for their participation and cooperation.

Source of Funding

This work was funded by the Borrow Foundation. The views expressed are those of authors and not necessarily of the Borrow Foundation.

References

1. Levy SM, Warren JJ, Broffitt B. Patterns of fluoride intake from 36 to 72 months of age. Journal of Public Health Dentistry 2003;63(4):211-20.
2. McClure F. Ingestion of fluoride and dental caries. American Journal of Diseases of Children 1943;66:362-9.
3. World Health Organization. Fluorides and oral health. Report of a WHO Expert Committee on Oral Health Status and Fluoride Use. World Health Organization Technical Report Series 1994;846:1-37.
4. Marthaler TM, editor. Monitoring of renal fluoride excretion in community preventive programmes on oral health. Geneva: World Health Organization; 1999.
5. Levy SM, Kohout FJ, Guha-Chowdhury N, Kiritsy MC, Heilman JR, Wefel JS. Infants' fluoride intake from drinking water alone, and from water added to formula, beverages, and food. Journal of Dental Research 1995;74(7):1399-407.
6. Levy SM, Warren JJ, Davis CS, Kirchner HL, Kanellis MJ, Wefel JS. Patterns of fluoride intake from birth to 36 months. Journal of Public Health Dentistry 2001;61(2):70-7.
7. Marshall TA, Levy SM, Broffitt B, Eichenberger-Gilmore JM, Stumbo PJ. Patterns of beverage consumption during the transition stage of infant nutrition. Journal of the American Dietetic Association 2003;103(10):1350-3.
8. Clovis J, Hargreaves JA. Fluoride intake from beverage consumption. Community Dentistry and Oral Epidemiology 1988;16(1):11-15.
9. Levy SM, Warren JJ, Broffitt B, Hillis SL, Kanellis MJ. Fluoride, beverages and dental caries in the primary dentition. Caries Research 2003;37(3):157-65.
10. Zohouri FV, Rugg-Gunn AJ. Sources of dietary fluoride intake in 4-year-old children residing in low, medium and high fluoride areas in Iran. International Journal of Food Science & Nutrition 2000;51(5):317-26.
11. Ophaug RH, Singer L, Harland BF. Dietary fluoride intake of 6-month and 2-year-old children in four dietary regions of the United States. American Journal of Clinical Nutrition 1985;42(4):701-7.
12. Zohouri FV, Rugg-Gunn AJ, Fletcher ES, Hackett AF, Moynihan PJ, Mathers JC, et al. Changes in water intake of Northumbrian adolescents 1980 to 2000. British Dental Journal 2004;196(9):547-52; discussion 537.
13. Martinez-Mier E, Cury J, Heilman J, Levy S, Li Y, Maguire A, et al. Development of standard fluoride analytical methods: direct analysis. Caries Research 2004;38:372.
14. Nelson M, Atkinson M, Meyer J. A photographic atlas of food portion sizes. London: Ministry of Agriculture Fisheries and Food; 1997.
15. Holland B, Welch A, Unwin I, Buss D, Paul A, Southgate D, editors. McCance and Widdowson's The composition of foods. London: The Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food; 1992.
16. Department of Health. Dietary Reference Values for Food Energy and Nutrients for the United Kingdom. Report on Health and Social Subjects No 41.
17. Gregory J, Lowe S, Bates C, Prentice A, Jackson L, Smithers G, et al. National Diet and Nutrition Survey: young people aged 4 to 18 years. London: The Stationery Office; 2000.
18. Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. Human Nutrition - Clinical Nutrition 1985;39 Suppl 1:5-41.
19. Bingham S. The use of 24-h urine samples and energy expenditure to validate dietary assessments. American Journal of Clinical Nutrition. 1994;59(1 Suppl):227S-231S.
20. Taves D. Separation of fluoride by rapid diffusion using hexamethyldisiloxane. Talanata 1968;15:969-74.
21. Soto-Rojas A, Cury J, Heilman J, Levy S, Li Y, Maguire A, et al. Development of standard fluoride analytical methods: Precision/trueness testing for diffusion techniques. Caries Research 2005;39:313.

22. Martinez-Mier E, Cury J, Heilman J, Levy S, Li Y, Maguire A, et al. Development of standard fluoride analytical methods: pilot study. Caries Research 2004;37:291.
23. Bingham S, Margettes B. Assessment of food consumption and nutrient intake. In: Margettes BM, Nelson M, editors. Design concepts in nutritional epidemiology: Oxford Medical Publications; 1991.
24. Brooks GA, Butte NF, Rand WM, Flatt JP, Caballero B. Chronicle of the Institute of Medicine physical activity recommendation: how a physical activity recommendation came to be among dietary recommendations. American Journal of Clinical Nutrition 2004;79(5):921S-930S.
25. Torun B, Davies PS, Livingstone MB, Paolisso M, Sackett R, Spurr GB. Energy requirements and dietary energy recommendations for children and adolescents 1 to 18 years old. European Journal of Clinical Nutrition 1996;50 Suppl 1:S37-80; discussion S80-1.
26. Rojas-Sanchez F, Kelly SA, Drake KM, Eckert GJ, Stookey GK, Dunipace AJ. Fluoride intake from foods, beverages and dentifrice by young children in communities with negligibly and optimally fluoridated water: a pilot study. Community Dentistry & Oral Epidemiology 1999;27(4):288-97.
27. Kimura T, Morita M, Kinoshita T, Tsuneishi M, Akagi T, Yamashita F, et al. Fluoride intake from food and drink in Japanese children aged 1-6 years. Caries Research 2001;35(1):47-9.
28. Zohouri FV, Rugg-Gunn AJ. Total fluoride intake and urinary excretion in 4-year-old Iranian children residing in low-fluoride areas. British Journal of Nutrition 2000;83(1):15-25.
29. Guha-Chowdhury N, Drummond BK, Smillie AC. Total fluoride intake in children aged 3 to 4 years—a longitudinal study. Journal of Dental Research. 1996;75(7):1451-7.
30. Haftenberger M, Viergutz G, Neumeister V, Hetzer G. Total fluoride intake and urinary excretion in German children aged 3-6 years. Caries Research 2001;35(6):451-7.
31. Martinez-Mier EA, Soto-Rojas AE, Urena-Cirett JL, Stookey GK, Dunipace AJ. Fluoride intake from foods, beverages and dentifrice by children in Mexico. Community Dentistry & Oral Epidemiology. 2003;31(3):221-30.
32. Villa A, Anabalon M, Cabezas L. The fractional urinary fluoride excretion in young children under stable fluoride intake conditions. Community Dentistry & Oral Epidemiology 2000;28(5):344-55.
33. Schamschula RG, Duppenthaler JL, Sugar E, Un PS, Toth K, Barmes DE. Fluoride intake and utilization by Hungarian children: associations and interrelationships. Acta Physiologica Hungarica 1988;72(2):253-61.
34. Murray JJ, Rugg-Gunn AJ, Jenkins GN. Fluoride in caries prevention. 3 ed. Oxford: Wright/Butterworth-Heinemann; 1991.
35. Mahan L, Escott-Stump S. Food, Nutrition and Diet Therapy. 9th Ed. Philadelphia, Pennsylvania: W.B. Saunders Company; 1996.