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The association between fluoride in drinking water and dental caries in Danish children. Linking data from health registers, environmental registers and administrative registers

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Abstract – Objectives: To study the association between fluoride concentration in drinking water and dental caries in Danish children. *Methods:* The study linked registry data on fluoride concentration in drinking water over a 10-year period with data on dental caries from the Danish National Board of Health database on child dental health for 5-year-old children born in 1989 and 1999, and for 15-year-old children born in 1979 and 1989. The number of children included in the cohorts varied between 41.000 and 48.000. Logistic regression was used to assess the correlations, adjusting for gender and taxable family income as a proxy variable for socioeconomic status. *Results:* Fluoride concentration in drinking water varied considerably within the country from very low (<0.10 mg/l) to more than 1.5 mg/l. Only little variation was found over the 10-year study period. Dental caries in both 5-year-olds and 15-year-olds decreased over the study period. An inverse relation between the risk of dental caries and fluoride concentration in drinking water was found in both primary and permanent teeth. The risk was reduced by approximately 20% already at the lowest level of fluoride exposure (0.125–0.25 mg/l). At the highest level of fluoride exposure (>1 mg/l), a reduction of approximately 50% was found. Similar findings were found if analysis was limited to children residing in the same place during the entire study period. *Conclusions:* The study confirmed previous findings of an inverse relation between fluoride concentration in the drinking water and dental caries in children. This correlation was found in spite of the extensive use of fluoridated toothpaste and caries-preventive programs implemented by the municipal dental services in Denmark. Linking Danish health registers with environmental and administrative registers offers an opportunity for obtaining sample sizes large enough to identify health effect, which otherwise could not be identified.

Key words: caries; fluoride

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The inverse relation between the fluoride concentration of drinking water and dental caries has been known for decades, and drinking water fluoridation for caries prevention is recommended by health authorities (1). Recently, however, a systematic review has questioned the quality of the evidence on which this recommendation is based (2).

In Denmark, the inverse relation between the fluoride concentration of drinking water and dental caries was demonstrated for the first time in 1965 by Møller (3). Drinking water fluoridation was never implemented in Denmark, but in the mid-1960s fluoride toothpaste was introduced to the Danish market, and today almost all toothpaste sold in Denmark contains fluoride. The caries-preventive effect of fluoride toothpaste is very well-documented (4), and it has been suggested that it is one of the most important causes of the decrease observed in dental caries in Danish children (5). In spite of the extensive use of fluoridated toothpaste, Ekstrand et al. (6) found that a large part of the inter-municipal variation in caries in children and adolescents could be explained by variation in drinking water fluoride concentrations. Their data were, however, aggregated at the municipal level and thus did not utilize the information on intra-municipality variation in fluoride concentration in drinking water and dental caries in children and adolescents.

Danish authorities operate a number of registers on environmental factors, socioeconomic factors and health conditions, and data in these registers can be linked to the individual citizen using the unique 10-digit number assigned to all citizens upon birth. Such registers offer an obvious possibility for studying associations between health conditions and, e.g. environmental and socioeconomic conditions. Linking health and environmental registers at the level of the individual, the present study aims to investigate whether an association exists between the drinking water fluoride concentration and the caries experience among Danish children and adolescents despite the widespread use of fluoridated toothpaste.

Materials and methods

Data sources

The present study used data from The Central Population Register (CPR), The Database on Oral Health (SCOR) of The Danish National Board of Health, The Jupiter Database [Geological Survey of Denmark and Greenland (GEUS)], The Building and Dwelling Register (BBR) and The Tax Register (SKAT).

The CPR register is a nationwide civil register in which a unique personal identification number (CPR number) identifies each citizen in Denmark. The register comprises name, present and past addresses, date and place of birth, gender (encoded in the CPR number), civil status, CPR number of spouse and CPR number of parents. The data are continuously updated. The SCOR Register contains data from the municipal dental clinics, which are collected when the children are seen for their regular dental examination (7). In Denmark, the municipalities are responsible for offering free, comprehensive, diagnostic, preventive and curative dental services to all children and adolescents from birth to the age of 18 years. This service enjoys a very high attendance rate (more than 95% in most municipalities). Data for the SCOR database are collected using a special computerized form, and the examinations are done by the child's dentist at the regular recalls. Diagnosis is mainly based on clinical findings. No formal calibration is performed, but the use of the system has been part of the undergraduate dental curriculum since it was implemented in 1972. As it has been in operation for more that 40 years, the diagnostic methods are well-established. Teeth extracted due to caries are distinguished from teeth extracted for other reasons by consulting the child's clinical record. Since 1993, reporting to SCOR has been reduced to the four age groups: 5, 7, 12 and 15 years. Dental diseases are recorded on a standard form for each child who is identified by his or her CPR number.

The BBR Register is a nationwide register containing information on buildings and dwellings. The Register is being continuously updated. Jupiter is GEUS' central water borehole database. It stores information about groundwater, environment and geotechnical boreholes. SKAT registers all individual income data relevant for tax purpose and can be identified by the individual's CPR number. In this project, family income was defined as the total taxable income at the time of measuring the outcome (dental caries) for all persons living at the same address as the child, and at the same time registered in the CPR register as the parents of that child.

Data linkage

The study was based on three cohorts of children born in 1979, 1989 and 1999 (Fig. 1). The children were identified in the CPR Register and their data

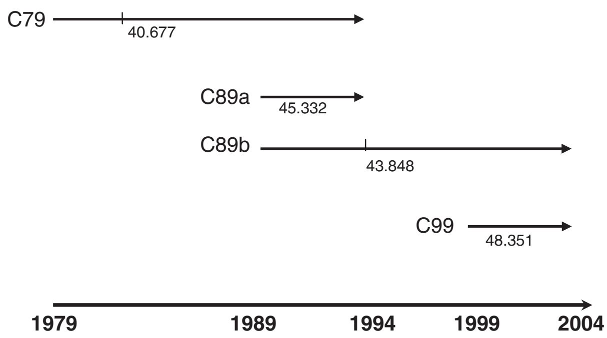

Fig. 1. Study cohorts, designated by year of birth. Arrowheads indicate SCOR registration. The number below each line is the total number of children in the cohort.

were linked to the data in SCOR using the CPR number and transformed addresses from the CPR Register.

Data linking was restricted to addresses which, according to the BBR, were supplied by a public or a private water work supplying 3–9 households. This limitation was necessary because of the very sporadic data on fluoride concentration in drinking water from private boreholes, wells or reservoirs. For a waterworks to be included, there had to be at least two values available for the period 1994–2004; if less than 5 analyses were available for the period, more than 5 years should separate the analyses. Data from waterworks that met the inclusion criteria were aggregated at waterworks level. The median fluoride concentration was calculated.

The processing of the fluoride data in the Jupiter database produced a digital map featuring the fluoride concentration in the water from the nearest waterworks at any given point (so-called Thiessen polygons) (8). Information on fluoride concentration was transferred to all address points where information on dental caries was available.

Regional variation in fluoride concentration was much greater than seasonal variation, the latter being almost zero during the years (data not shown), and it was therefore considered justifiable to exclude analyses from the period up to 1993 from the data linking because of the poor quality control of the analyses prior to this point in time. No significant association between boring depth and fluoride concentration could be demonstrated (data not shown).

Among the original 4000 waterworks with 50 000 analyses, 3000 waterworks with a total of 34 000 analyses met the inclusion criteria.

For the cohort born in 1979 (Cohort C79), data on family income during the individual's childhood and youth were not available. Thus, for this cohort, no adjustment could be made for the effect of family income. For the other cohorts, family income in 2004 was used.

The Danish Data Protection Agency granted permission to process the data (File # 2002-53-0759).

Data analysis

All data were converted to STATA format using StatTransfer version 7 (Circle Systems, Seattle, WA, USA) and were analysed using STATA version SE 8.2 (StataCorp LP, College Station, TX, USA).

The fluoride exposure was calculated as a weighted mean by summing the product of the fluoride concentration at each address and the time the person has dwelled at the address divided by the years of known exposure.

The outcome analysed was DMFS for 15-year olds and dmfs for 5-year olds for permanent and primary teeth, respectively. The diagnostic cut-off point used for caries was cavitation.

To adjust for the importance of gender and family income, the influence of fluoride in the drinking water was estimated by logistic regression, using two models. In one model, we estimated the probability of a DMFS or dmfs of ≥2 as a function of fluoride, family income and gender. The value of ≥2 was chosen for dichotomization to allow for diagnostic uncertainties in routine clinical data and to secure sufficiently large numbers in the subgroups for the logistic regression analysis. To estimate the influence of drinking water fluoride on children with high levels of caries, a similar analysis was carried out using a DMFS of ≥6 for dichotomization.

As the distribution of outcome was not Gaussian, nonparametric tests for trends (nptrend) and groupings (Kruskall-Wallis) were used. Finally, the multivariate association was assessed by logistic regression analysis. All logistic regression models were subsequently tested by the Hosmer-Lemeshow test. In spite of the non-Gaussian distributions, we also report mean values and standard deviations, as these parameters are commonly reported in studies on drinking water fluoride and caries.

Results

Drop-out analysis

Table 1 show that approximately 70% of the children in each age group were included in the

Table 1. Total number of children in each age group according to official national statistics (9), and number and percentage of children included in the study

Year	Age (years)	Total no.	Included (%)
1994	5	59.752	40.677 (68.1)
	15	63.449	45.332 (71.4)
2004	5	67.283	43.848 (65.2)
	15	62.290	48.290 (77.5)

study according to official national statistics (9). Children not included in the analyses had no match between the different registries. A drop-out analysis was performed for the children followed from 1989 to 2004 (Cohort C89b). The children who had a match between the SCOR register and the CPR register had a higher median family income, than those who did not have matching data in these two registers (422.999 DKr versus 292.322 DKr). Of those children, who had data in the SCOR register, those with complete data in the BBR register had a higher median family income than those who did not have complete data in the BBR register (447.616 DKr. versus 277.387 DKr.), and a lower median DMFS (1 versus 2). This later analysis indicates that the children included in the analysis are from families with a higher family income and have a slightly lower caries level.

Fluoride concentration in the drinking water

The fluoride concentration in the drinking water varied considerably within the country (Fig. 2). Drinking water in the Western part of the country had the lowest values (<0.01 mg/l) and drinking water in the South-Eastern part reached values of 0.40 mg/l. Concentrations >1.00 mg/l were only found in relatively few locations, and only in the Southern part of Zealand and on the island of Bornholm in the Baltic Sea.

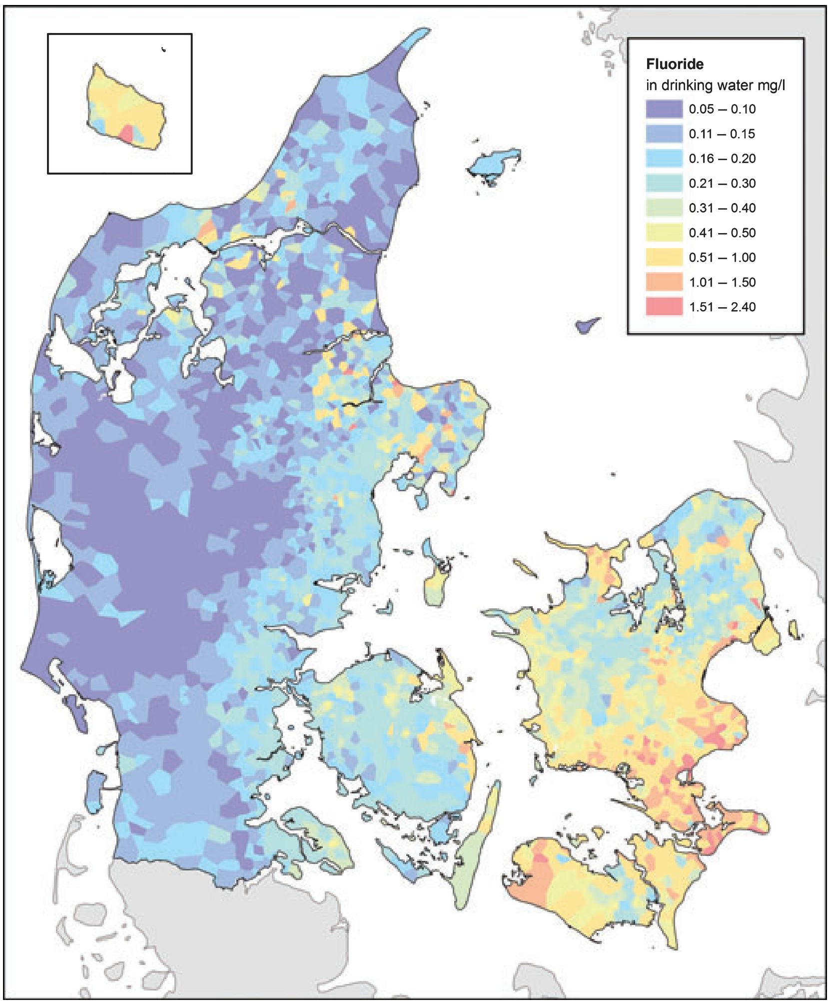

Fig. 2. Map of Denmark showing the fluoride concentration in drinking water ('Thiessen map'). The island of Bornholm is located in the Baltic Sea, but is shown in the upper left corner of the map.

Table 2. Descriptive data on dental caries in 5- and 15-year olds according to year of examination

Cohort	Year of birth	5 years (dmfs) Mean dmfs (SD)	Proportion with dmfs ≥2	Median dmfs	90% percentile	15 years (DMFS) Mean DMFS (SD)	Median DMFS	Proportion with DMFS ≥2	Proportion with DMFS ≥6	90% percentile
C79	1979	–	–	–	–	3.97 (5.47)	2	45.63%	20.73%	10
C89a	1989	2.01 (4.92)	20.77%	0	6	–	–	–	–	–
C89b	1989	–	–	–	–	2.70 (4.35)	1	33.67%	12.29%	7
C99	1999	1.44 (4.13)	15.23%	0	4	–	–	–	–	–

Dental caries in 5- and 15-year olds

Mean values of both dmfs and DMFS were low (Table 2). Mean dmfs for 5-year olds was below 2 for both children born in 1989 (Cohort C89a) and children born in 1999 (Cohort C99). The 90% percentile had decreased from 6 for children born in 1989 to 4 for children born in 1999, corresponding to a decrease of approximately 30%. Mean DMFS for 15-year olds was below 4 for both of the cohort born in 1979 (Cohort C79) and the cohort born in 1989 (Cohort C89b). The 90% percentile had decreased from 10 for children born in 1979 to 7 for children born in 1989, corresponding to a decrease of approximately 30%.

Association between dental caries and fluoride concentration in the drinking water

Dental caries in the primary dentition (dmfs ≥ 2) of 5-year olds showed a negative association with fluoride concentration in the drinking water in children born in 1989 after adjustment for family income and gender (Cohort C89a; Table 3). Similar results were found for children born in 1999 (Cohort C99) (Table 4).

A negative association was also found between fluoride concentration in the drinking water and caries in the permanent dentition (DMFS ≥ 2 or DMFS ≥ 6) of 15-year olds born in 1979 (Cohort C79) after adjustment for gender (Table 5), and for 15-year olds born in 1989 (Cohort C89b) after adjustment for family income and gender (Table 6).

Table 3. Association (OR and 95% confidence interval) between fluoride concentration in drinking water and caries in the primary dentition (dmfs ≥ 2) in 5-year-old children born in 1989 (Cohort C89a; n = 45.332)

	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]
Weighted mean fluoride exposure mg/l		
0–0.1249[b]	–	–
0.125–0.249	0.76 (0.72–0.81)	0.77 (0.73–0.82)
0.25–0.3749	0.65 (0.60–0.69)	0.66 (0.62–0.71)
0.375–0.99	0.57 (0.55–0.61)	0.58 (0.55–0.62)
≥1	0.51 (0.45–0.57)	0.53 (0.47–0.59)

[a]Adjusted for family income and gender.
[b]Reference group.

Table 4. Association (OR and 95% confidence interval) between fluoride concentration in drinking water and caries in the primary dentition (dmfs ≥ 2) in 5-year-old children born in 1999 (Cohort C99; n = 48.351)

	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]
Weighted mean fluoride exposure mg/l		
0–0.1249[b]	1	1
0.125–0.249	0.84 (0.79–0.90)	0.86 (0.80–0.91)
0.25–0.3749	0.86 (0.80–0.91)	0.86 (0.80–0.93)
0.375–0.99	0.77 (0.72–0.82)	0.78 (0.73–0.84)
≥1	0.69 (0.61–0.78)	0.74 (0.65–0.84)

[a]Adjusted for family income and gender.
[b]Reference group.

Of particular interest was that we observed a negative association between dental caries and fluoride concentration in the drinking water already at low levels of fluoride exposure (0.125–0.249 mg/l) both in the primary and the permanent dentition. Children with >1 mg/l exposure had half the odds of caries relative to children with 0–0.1249 mg/l exposure. A clear dose–response relationship was seen between fluoride concentration in drinking water and caries in all cohorts.

Discussion

The present study confirms the findings of numerous previous studies of a negative association between the fluoride concentration in drinking water and childhood caries. Previous studies have been criticized for insufficient confounder control, and it is therefore interesting to note that control for potentially strong confounders had little or no influence on the estimates in our study.

Data for the study were drawn from registries and are accordingly subject to the inherent weak-

Table 5. Association (OR and 95% confidence interval) between fluoride concentration in drinking water and caries in the permanent dentition (DMFS ≥ 2 and DMFS ≥ 6) in 15-year-old children born in 1979 (Cohort C79; n = 40.677)

	DMFS ≥ 2		DMFS ≥ 6	
	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]
Weighted mean fluoride exposure mg/l				
0–0.1249[b]	1	1	1	1
0.125–0.249	0.75 (0.71–0.80)	0.75 (0.70–0.79)	0.68 (0.64–0.72)	0.68 (0.64–0.73)
0.25–0.3749	0.56 (0.51–0.60)	0.58 (0.54–0.62)	0.48 (0.44–0.51)	0.50 (0.46–0.53)
0.375–0.99	0.50 (0.47–0.53)	0.51 (0.48–0.54)	0.38 (0.36–0.41)	0.40 (0.37–0.43)
≥1	0.49 (0.44–0.54)	0.53 (0.48–0.59)	0.36 (0.31–0.41)	0.37 (0.32–0.42)

[a]Adjusted for gender.
[b]Reference group.

Table 6. Association (OR and 95% confidence interval) between fluoride concentration in drinking water and caries in the permanent dentition (DMFS ≥ 2 and DMFS ≥ 6) in 15-year-old children born in 1989 (Cohort C89b; n = 43.848)

	DMFS ≥ 2		DMFS ≥ 6	
	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]
Weighted mean fluoride exposure mg/l				
0–0.1249[b]	1	1	1	1
0.125–0.249	0.78 (0.74–0.83)	0.77 (0.73–0.81)	0.73 (0.68–0.78)	0.72 (0.67–0.77)
0.25–0.3749	0.67 (0.63–0.71)	0.66 (0.62–0.70)	0.51 (0.47–0.56)	0.52 (0.48–0.57)
0.375–0.99	0.57 (0.54–0.60)	0.57 (0.54–0.61)	0.44 (0.41–0.48)	0.45 (0.42–0.49)
≥1	0.50 (0.45–0.55)	0.54 (0.49–0.60)	0.33 (0.28–0.39)	0.36 (0.31–0.43)

[a]Adjusted for family income and gender.
[b]Reference group.

nesses of any study based on data not primarily collected for research purposes. As for the data on drinking water fluoride concentration, a thorough quality control proved necessary. All data were reviewed and cleaned for various errors, i.e. errors in water analyses and typing errors at the individual waterworks. The resulting substantial amount of data, the 10-year observation period, and the extensive quality control all contributed to minimize sources of error in the fluoride data and the risk of bias.

Data to link a specific address to a specific waterworks were not available, and drinking water data therefore do not exist at the level of the individual. Moreover, in certain locations where the fluoride concentration varies significantly, even within a rather small area, some uncertainty prevails as to total exposure. However, we found the same association between the fluoride concentration in drinking water and dental caries in these areas as in the areas without these uncertainties.

The effect on the estimates of restricting the analyses to children with the same residence during the entire study period was negligible. This could either indicate that our exposure model is adequate, or that people predominantly move within the same geographical location with nearly the same fluoride concentration. Restriction of the analysis to children with the same place of residence during the entire study period reduced the sample size by half.

Data in the SCOR database are usually considered of sufficient quality for research purposes, and data have been shown to be fraught with relatively few inconsistencies (10). Dentists' knowledge of the fluoride concentration in the drinking water in the area where they work may, however, influence their criteria for operative caries therapy. As the major part of the dmfs/DMFS indices are the f/F-component, this may be an important source of bias. This factor could be assumed to be strongest in areas commonly known as 'fluoride areas' in Denmark, like the Southern part of Zealand and the island of Bornholm. As we observed a negative correlation between caries and fluoride concentration in drinking water also at low levels of fluoride concentration, this factor seems to have relatively little influence on our results.

Finally, confounder control will be limited to factors stored in the registries. One uncontrolled factor in the present study is ethnic background, which has been shown to be strongly correlated with dental caries in Danish children (11). On the other hand, children with non-Danish ethnic background only accounted for approximately 10% of the entire population in the two age groups in 2007 (Statistics Denmark).

The strength of using registry data is obviously the large sample sizes that can be obtained and the ensuing high statistical power of the analysis. In spite of the exclusion of individuals from the study due lack of data, lack of match between the various registers, etc., we obtained samples sufficiently large to identify an association between dental caries and fluoride concentration in drinking water, even at low levels of fluoride exposure (0.125–0.25 mg/l).

Ideally, a study of the association between dental caries and fluoride in drinking water should link data on the exposure, possible confounders and outcome at the level of the individual. In our study, data on caries, gender and family income fulfilled this requirement, while data on fluoride expose were only available at an aggregated level, although at a level rather close to that of the individual level.

The present study showed that it was possible to link data from the health, the environmental and the administrative registers within a reasonable time. The study also showed that linking these kinds of data requires access to registers with valid data on a large part of the population. The Danish registers seem to meet these criteria, but improvement could make them even more suited for research purposes.

Like in the present study, Ekstrand et al. (6) demonstrated a dose–response association between fluoride concentration in drinking water and caries and the effect was highest in the group with the highest exposure. They found that the effect was minimal at fluoride concentrations <0.3 mg/l, whereas the present study found a reduced risk even at fluoride concentrations below 0.3 mg/l.

Considering the high concentration of fluoride in toothpaste (up to 1.450 mg/l), it is remarkable to note the importance of fluoride from drinking water whose total contribution approximates 0.32–0.56 mg/day (at a fluoride concentration of 0.4 mg/l drinking water). One possible explanation is that in spite of the common use of fluoridated toothpaste in the population, some segments may not have sufficiently effective oral hygiene procedures to benefit fully from the caries-preventive effect of fluoridated toothpaste, and may therefore enjoy the advantage of fluoride from drinking water.

The caries experience among children has decreased markedly during the past 20 years. In particular, caries has almost been eliminated in the primary dentition of 5-year olds from high-income families. However, children of low-income families living in areas with low fluoride concentrations in the drinking water seem to be at increased risk of dental caries.

Acknowledgement

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