Health Effects of Public Water Fluoridation

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The Centers for Disease Control and Prevention (CDC) called fluoridation of municipal drinking water one of the 10 great achievements in public health of the 20th century (1). The recommended supplementation rate to prevent dental caries is 0.7-1.2 mg/L fluoride to water (2). The Academy of Nutrition and Dietetics recognizes the importance of oral health for overall health and endorses the practice of fluoridation (3).

The current literature recognizes environmental and behavioral factors associated with tooth decay, of which fluoride intake is but one. It has been suggested that high water fluoride levels are associated with risks of fluorosis, bone density changes and fracture, and cancer. With nearly 70 years of research available on the topic, this paper seeks to determine the overall impact of water fluoride concentration on the health of populations. This paper also intends to comment on the role of the dietitian in promoting oral health.

**Dental Caries**

**Caries Prevalence and Fluoridation**

Table 1 shows the results of seven studies that compared the risk of dental caries between populations exposed to high and low concentrations of fluoride in drinking water (4, 5, 6, 7, 8, 9, 10). Overwhelmingly, the evidence from this literature supports maintaining a fluoride concentration of approximately 1.0 ppm to reduce the risk of decayed, missing, and filled primary and permanent teeth (DMFT) in children and adolescents. Furthermore, multiple studies found an inverse relationship between fluoride concentrations in drinking water and a history of dental caries in youths (6, 7, 9, 10). These studies did not control for subject migration (4, 5, 7, 9, 10). Furthermore, the subjects may have had access to fluoride-containing oral care products (5, 7-10). It was averred, though, that all subjects had equal access to and use of these products (8, 10).

**Caries Prevalence after Fluoridation Ceases**

The importance of systemic water fluoridation for controlling dental caries is challenged by some studies investigating the effect of fluoridation cessation. Several studies were reviewed which observed tooth
Table 1: Summary of Studies Investigating Rates of Decayed, Missing and Filled Teeth between Areas with High and Low Fluoride Concentrations in Drinking Water

<table>
<thead>
<tr>
<th>Author</th>
<th>Year of Publication</th>
<th>Study Type, Length (years)</th>
<th>High Fluoride Population (Concentration)</th>
<th>Low Fluoride Population (Concentration)</th>
<th>Subject Age Range (years)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jones et al. (4)</td>
<td>1997</td>
<td>Cross-sectional, 4 years (1991-1994)</td>
<td>North Tyneside and Newcastle (1 ppm*) and Hartlepool (1.22 ppm)</td>
<td>Salford, Trafford (not given)</td>
<td>5</td>
<td>mean dmft† incidence was lower in areas with high water fluoride than low water fluoride (P&lt;0.001)</td>
</tr>
<tr>
<td>Riley et al. (5)</td>
<td>1999</td>
<td>Cross-sectional, 2 years (1993-1994)</td>
<td>7 wards in UK with fluoridated public water</td>
<td>7 wards in UK with non-fluoridated public water</td>
<td>5</td>
<td>mean dmft 0.87 (SD 4.1) in high fluoride areas vs. 1.8 (SD 1.1) in low fluoride areas; (P&lt;0.001)</td>
</tr>
<tr>
<td>McDonagh et al. (6)</td>
<td>2000</td>
<td>Meta-analysis, 32 years (1965-1997)</td>
<td>26 studies incorporated DMFT outcomes</td>
<td>5-14</td>
<td></td>
<td>range of mean decrease (median) in DMFT‡ in areas with high fluoride= 0.5-4.4 (SD: 2.55)</td>
</tr>
<tr>
<td>Gillcrist et al. (7)</td>
<td>2001</td>
<td>Cross-sectional, 1 year (1996-1997)</td>
<td>Fluoridated communities in Tennessee (1.0 ppm*)</td>
<td>Non-fluoridated communities in Tennessee (&lt;0.3ppm)</td>
<td>5-11</td>
<td>dfs• score 21% lower in high fluoride communities (mean 8.79 vs. 6.94) ; DMFS▫ score 25% lower in high fluoride communities (mean 1.02 vs. 0.77)</td>
</tr>
<tr>
<td>Binbin et al. (8)</td>
<td>2004</td>
<td>Cross-sectional, 1 year (1995)</td>
<td>4 villages in China (1.02-3.68 mg/L)</td>
<td>28 cities in China (0.007-0.700 mg/L)</td>
<td>5-18</td>
<td>DMFT‡ negatively associated with water fluoride levels, no linear relationship found</td>
</tr>
<tr>
<td>Evans et al. (9)</td>
<td>2009</td>
<td>Longitudinal, 10 years (1993, 2003)</td>
<td>Hawksbury, Wentworth, Australia (1.0 mg/L*)</td>
<td>Blue Mountain area, Wentworth, Australia (fluoridation to 1.0 mg/L begun 1992)</td>
<td>5-11</td>
<td>dmft† at baseline lower (P=0.05) in Hawksbury than Blue Mountain, rates similar in 2003; DMFT• showed secular trend towards lower dental caries over 10 years</td>
</tr>
<tr>
<td>Armfield (10)</td>
<td>2011</td>
<td>Cross-sectional, 1 year (2002)</td>
<td>Areas of Australia (≥ 0.7 ppm)</td>
<td>Areas of Australia (≤ 0.3 ppm)</td>
<td>5-15</td>
<td>dmft 25.8-65.8% lower depending on subject age in areas of high water fluoride, OR 1.34 (CI 0.16-0.42); DMFT• 12.7%-51.0% lower depending on subject age in areas of high water fluoride, OR 1.24 (CI 1.21-1.28; P&lt;0.001 for both outcomes</td>
</tr>
</tbody>
</table>

*Supplemented fluoride levels, all others refer to natural fluoride levels.  
†dmft: Decayed, missing and filled primary teeth  
‡DMFT: Decayed, missing and filled teeth, reporting primary and permanent teeth together  
•dfs: Decayed and filled surfaces of primary teeth  
▫DMFS: decayed, missing and filled surfaces of permanent teeth  
•DMFT: Decayed, missing and filled permanent teeth.
decay prevalence after public water fluoridation was discontinued (11, 12, 13, 14). The authors of these studies all hypothesized that caries prevalence in children would increase after fluoridation stopped, citing previous research. However, the prevalence of dental caries in the study populations remained unchanged or decreased. The results of this research are summarized in Table 2.

Multiple factors may have kept dental caries rates low after fluoridation ended. Künzel et al. (12) noted that use of dental sealants increased in Germany after 1990. Maupomé et al. (14) noted that controlling for the protective effect of dental sealants attenuated their findings, implying that dentists in non-fluoridated communities were more proactive in caries prevention. However, Seppä et al. (11) noted a decrease in dental sealants in Finland between their initial and follow-up studies. Nevertheless, increased access to dental care and fluoride toothpaste were cited as important factors in maintaining low rates of dental caries (11, 12, 14). Changes in the rates of dental caries may have been too small to detect due to low overall caries prevalence (11, 14). Reduced sugar consumption may have influenced these unexpected results, also (12).

Künzel and Fischer’s assessment of La Salud, Cuba (13) went against the trend noted in the other studies. Between 1973 and 1997 Cuba lacked a supply of toothbrushes, toothpaste, and materials for dental sealants. Sugar consumption in Cuba is generally high. However, fluoride mouth rinses and varnishes were distributed regularly in schools, and these interventions may have abated the development of caries in children. Overall, the anti-cariogenic factors noted in the other studies were not found in La Salud.

Current Risk Factors for Dental Caries

Recent research has found fluoridation to be a less important factor in controlling dental caries. Griffin et al. (15) analyzed data from the National Institute of Dental Research (NIDR) Children’s Study. It was found that municipal water fluoridation benefits both children living in the community and those who are exposed to moderate or high levels of diffusion effect, i.e. consuming food and beverages produced in fluoridated communities while living in areas with low water fluoride concentration.
Table 2: Summary of Studies Investigating the Effect of Ceasing Systemic Drinking Water Fluoridation

<table>
<thead>
<tr>
<th>Author</th>
<th>Year of Publication</th>
<th>Area Studied</th>
<th>Year Fluoridation Ceased</th>
<th>Years in which Data Were Collected (Length of time without fluoridation)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seppä et al. (11)</td>
<td>1998</td>
<td>Kuopio, Finland</td>
<td>1992</td>
<td>1992 and 1995 (3 years)</td>
<td>Mean DMFS§ did not change in children aged 6,9,12, and 15 years; a clinically important reduction in mean DMFT‡ (18%) was seen in 15 year old subjects</td>
</tr>
<tr>
<td>Künzel et al. (12)</td>
<td>2000</td>
<td>Spremberg, Germany</td>
<td>1993</td>
<td>1975, 1981, 1993, 1996 (3 years)</td>
<td>Mean DMFT‡ did not change in children aged 6-18 years</td>
</tr>
<tr>
<td>Künzel and Fischer (13)</td>
<td>2000</td>
<td>La Salud, Cuba</td>
<td>1990</td>
<td>1982 and 1997 (7 years)</td>
<td>Mean DMFT‡ did not change in children aged 6-13 years; mean DMFT‡ decreased from 2.1 to 1.1 (P&lt;0.05) in 12-13 year old children.</td>
</tr>
<tr>
<td>Maupomé et al. (14)</td>
<td>2001</td>
<td>Three towns in British Columbia, Canada</td>
<td>1993</td>
<td>1993-1994 and 1997-1998</td>
<td>Mean D1D2MFS~ decreased (P&lt;0.01) in a cohort of school children; rates of dental caries per 100 at-risk-surfaces and per 100 pit-and-fissure tooth surfaces were lower (P&lt;0.01) for students in grades 5-6 and 11-12 compared to a neighboring town which continued to fluoridate.</td>
</tr>
</tbody>
</table>

§DMFS: Decayed, missing and filled surfaces, reporting primary and permanent teeth together
‡DMFT: Decayed, missing and filled teeth, reporting primary and permanent teeth together
~D1D2MFS: decayed (non-cavitated), decayed (cavitated), missing, and filled surfaces of permanent teeth
However, the study also found a significant protective effect of dental sealants and regular use of fluoride rinses or varnishes. National Health and Nutrition Examination Survey (NHANES) data reviewed by Ditmyer et al. (16) found multiple factors affected DMFT scores amongst youths aged 12-19 years in Nevada. The case subjects (n=2,124) were the 30% of Nevada youths with the highest DMFT scores. The control group was a cohort of caries-free Nevada youths (n=2,045). Subjects from non-fluoridated communities were more likely to be in the case group compared with subjects from fluoridated communities (OR 2.04, CI 0.41-0.59). Other risk factors included having no dental sealants vs. having dental sealants (OR 1.52, CI 1.39-1.65), and lacking dental insurance vs. being insured (OR 1.50, CI 1.25-1.75). Chankanka et al. (17) analyzed raw data from the Iowa Fluoride Study. Non-cavitated caries were significantly inversely associated with both tooth brushing frequency and high socioeconomic status. There was no association found between dental caries and composite water fluoride in this study. Jones et al. (4) and Riley et al. (5) noted that children of low socioeconomic status have higher caries rates.

The continued importance of wide-spread fluoridation as a means to control dental caries can rightfully be questioned given the body of literature. Many researchers affirm that the efficacy of the practice is reason both to continue systemic fluoride supplementation and to increase the percentage of homes receiving fluoridated drinking water (4-10). However, expanding fluoridation may be superfluous in areas where fluoride toothpaste and basic dental care are easily accessible. A superior option in these areas may be to subsidize regular preventative dental care to populations of low socioeconomic status and promote good oral care habits across the population.

Ceasing fluoridation in areas already supplemented should also be conducted with forethought. Cessation in select areas may not increase caries rates (11-14). However, the importance of the diffusion effect described by Griffin et al. (15) suggests that wide spread discontinuation may lead to a rise in dental caries rates. This should be considered especially if dental care and other sources of fluoride are scarce.

**Fluorosis**
Grobler et al. (18) investigated fluorosis in South African children (n=77) aged 10-15 years from areas where well water offered naturally low (0.19 mg/L) and high (3.00 mg/L) fluoride concentrations. There was a significantly higher mean fluorosis index score in areas with high fluoride concentration (3.6 mg/L vs. 1.3 mg/L). Furthermore, severe fluorosis was found in 30% of subjects from the high fluoride area but none of the subjects from the low fluoride area. The meta-analysis by McDonagh et al. (6) reviewed 88 studies comparing fluorosis between subjects exposed to high vs. low fluoride concentrations in drinking water. The researchers calculated a pooled prevalence of fluorosis of 48% when water was fluoridated to 1 ppm. They also noted a clear dose-dependent effect of fluoride concentration in drinking water and increased prevalence of fluorosis. Binbin et al. (8) also found that fluorosis increased with fluoride concentration in drinking water (r²=0.9164) in subjects aged 15-19 years.

The research indicates that prevalence of fluorosis increases in relation to fluoride concentrations in drinking water. It should be noted that the high fluoride exposure group studied by Grobler et al. (18) was accessing wells with a fluoride concentration three times the recommended anti-cariogenic concentration, so the extent of fluorosis found in this study should not be anticipated in municipalities that fluoridate within CDC guidelines.

**Bone Mineralization during Growth**

Limited research is available regarding the effects of water fluoridation on the skeleton during growth. Grobler et al. (18) also measured bone mineral concentration (BMC) and density (BMD) of the ulna in their subjects. Statistics were analyzed by age group and by gender. BMC was higher (P>0.05) in girls from the high fluoride area than in boys from the low fluoride area in the 12-13 year old age group. Also, BMD was greater (P>0.05) in the 14-15 year old age group for girls and boys from the high fluoride area compared to girls from the low fluoride area. BMD was significantly higher in girls from the high fluoride area compared to the low fluoride area in both the 11-12 and 13-14 year old age groups; BMD was significantly higher in boys from the high compared to the low fluoride area in the 14-15 year old age group.
Levy et al. (19) investigated BMC and BMD of the hip, spine, and whole body in participants of the Iowa Bone Development Study. BMD was measured in a cohort of boys and girls at five (n=470), eight (n=538) and 11 (n=481) years. Parents completed surveys regarding fluoride intake through water and other sources, and children’s body weights. These were used to estimate daily fluoride intake by weight (mg F/kg/d). All regression coefficients were adjusted for subject age, height, weight, and Tanner stage. No correlation between mg F/kg/d and BMC or BMD of the whole body, hip, or spine was observed for any age group in boys or girls.

Arnold et al. (20) studied the effect of long term exposure to fluoridated drinking water on BMD in female university students in Saskatchewan, Canada. The subject pool consisted of 18-25 year old women from Regina (n=24) where water is not fluoridated, and Saskatoon (n=33) where water has been fluoridated to 1.0 mg/L since 1954. BMD of the APS and VLS were greater (P<0.05) in subjects from Saskatoon than those from Regina. No difference was found in TB or PF bone mineral density.

Given the sparse amount of research, it is difficult to draw conclusions regarding exposure to fluoride in drinking water and bone mineral status in younger people. Grobler et al. (18) found the effect of fluoridated water on BMD and BMC increased over time, but the subjects were exposed to water with a fluoride concentration far in excess of that recommended to prevent caries. Arnold et al. (20) examined young women only. While it is possible that exposure to fluoridated water may enhance skeletal mineralization during growth more research is needed to confirm the current findings.

**Fluoride Concentrations in Drinking Water and Fracture in Adults**

Pharmacological doses of fluoride are used to prevent fractures in patients with or at risk for osteoporosis (21, 22). However, in some studies lower bone density in the peripheral skeleton has been found with high doses of fluoride(22). The long-term effect of water fluoride levels on fracture rates, particularly hip fracture, has been investigated to determine if there is a protective or detrimental effect.

Suarez-Almazor et al. (23) compared the rates of hip fracture hospitalization from 1981 to 1987 for men and women aged 45 years and older in two Alberta, Canada cities. Municipal water has been fluoridated to 1 mg/L since 1967 in Edmonton. In Calgary, the fluoride concentration in municipal water
is roughly one third as high. Hip fracture rates were similar between the two cities in all age groups for women analyzed alone and when men and women were analyzed together. However, the hip fracture rate ratio was significantly higher in Edmonton for men aged 65+ (RR 1.12, 95% CI 1.00-1.27) and for men aged 45+ (RR 1.13, 95% CI 1.01-1.24).

In another retrospective study, Jacobson et al. (24) examined records of hip fracture in men and women aged 50 years and older for 10 years before (1950-1959) and after (1960-1969) the implementation of public water fluoridation in the city of Rochester, MN. After fluoridation, the rate of hip fracture in women dropped from 781 to 613 per 100,000 person-years. The relative risk of hip fracture for women associated with fluoridation was 0.60 (95% CI 0.42-0.85). For men, the hip fracture rate increased from 172 to 219 per 100,000 person-years after fluoridation. However, this change was not significant and the relative risk for men was calculated to be 0.78 (95% CI 0.73-1.66).

Karagas et al. (25) used Medicare records and U.S. Census data regarding fluoride in public water supplies from 1986 to 1990 to compare water fluoride levels and hip fracture rates by county across the United States in men and women aged 65-89 years. Hip fracture rates were not found to be associated with fluoride levels. Hillier and colleagues (22) conducted a case-controlled study of hip fracture in men and women aged 50 years and older from Cleveland County, UK over a 17 month period. This study also found no association between hip fracture and fluoride levels in water. Sowers et al. (21) examined hip fracture risk in women aged 20 to 92 years from three communities with diverse mineral composition in their respective water supplies. Data were adjusted for other factors known to affect fracture risk including tobacco use, age, and menopause status. Again, fracture rates were similar regardless of water fluoride levels.

Two of these studies explored additional fracture sites (21, 25). Sowers et al. (21) found no effect of water fluoride levels on fracture of the lumbar spine or distal radius in women after correcting for confounding factors. Karagas et al. (25) investigated geographical trends in fracture of the distal forearm, proximal humerus, and distal tibia and fibula. Fracture of the proximal humerus in men was associated with higher fluoride levels in water (RR 1.23; 95% CI 1.06-1.43), as was fracture of the distal forearm.
In other words, men living in areas with high water fluoride levels had a 23% and 16% increased fracture risk in the humerus and forearm, respectively. Additionally, a large meta-analysis found heterogeneous results among 29 studies of the effect of fluoridation on all fractures (6). Overall, the effect on risk of fracture amongst areas with fluoridated drinking water was evenly distributed across the line of no effect.

Although Suarez-Almazor et al. (24) found a statistically increased rate of hip fracture for men living in a fluoridated community the effect is clinically negligible with only 0.19 additional fractures per 100 person-years in Edmonton. Additionally, Edmonton has more industrial and manufacturing jobs while Calgary is described as white collar. The different work environments may present different overall risks of injury. Similarly, the methodology employed by Karagas et al. (25) did not control for employment, activity level, socio-economic status, or other health factors. Jacobsen et al. (24) note the trend in hip fracture rates in Rochester, MN began to change before fluoridation began, again suggesting other causes for the statistical changes observed in the study. McDonagh et al. (6) found that studies of longer than 10 years tended to see a decrease in fracture rates in areas with fluoridated water, but the meta-regression and could not control for confounding factors. The evidence indicates fluoridation of the public water supply does not offer protection against fractures in older adults. Some results suggest an increased risk of fracture for older men related to fluoridated water. This risk and its clinical importance are both unconfirmed.

**Fluoride Concentrations in Drinking Water and Cancer**

Four studies (26, 27, 28, 29) which investigated the possible connection between cancer in human populations and the fluoride concentration of drinking water were reviewed. In a retrospective epidemiological study Chilvers and Conway (26) looked for an association between naturally occurring fluoride levels and cancer mortality in various regions of England. Areas with high (≥ 1.0 ppm), medium (0.5-0.99 ppm), low (≥ 0.2 ppm), and very low (≥ 0.1 ppm), concentrations of fluoride in drinking water were identified. Cancer mortality data from 1969 to 1973 for multiple cancers were examined in these areas and compared between high and low, and between medium and very low, fluoride areas. Men had
higher (P<0.05) cancer rates overall, and higher (P<0.05) rates of bladder cancer in areas with medium fluoride vs. very low fluoride. Significantly higher rates of buccal/oral cavity cancer as well as rectal cancer were found in men from high fluoride vs. low fluoride areas, but no other differences were found.

A similar study by Yang and colleagues (27) compared cancer mortality in men and women from 1982 to 1991 in Taiwan between 10 municipalities identified as having the highest natural water fluoride concentrations and 10 with non-fluoridated water supplies. Increased risk (P<0.05) of bladder cancer was found for women in municipalities with high water fluoride levels; rates of all other cancers were similar for men and women. Comber et al. (28) studied osteosarcoma rates on the island of Ireland between 1994 and 2006. Urban areas of the Republic of Ireland receive fluoridated water. Northern Ireland (NI) and rural areas of the republic of Ireland do not receive fluoridated water. Osteosarcoma diagnoses were compared between the two populations. There was no difference in osteosarcoma rates between the urban and rural dwelling study subjects. The researchers did find osteosarcoma rates for females aged ≤ 25 years were significantly higher in the Republic of Ireland versus Northern Ireland, but the highest rate was seen in rural areas of the Republic of Ireland, an area assumed to be non-fluoridated. Levy and Leclerc (29) investigated incidence of osteosarcoma in the United States from 1999 to 2006 as related to fluoride in drinking water. The CDC Wonder Database was used to determine diagnosis rates of osteosarcoma in children aged 5-19 between the years 1999 and 2006 between areas where either ≥ 85% or ≤ 30% of residents receiving fluoridated drinking water. The rates of osteosarcoma did not differ between the high and low fluoridation areas. Additionally, McDonaugh et al. (6) examined 26 studies and found no clear causal link between fluoridation and cancer. They noted that heterogeneity among studies precluded formal regression analysis.

All of these authors note methodological flaws. Both Chilvers and Conway (26), and Yang et al. (27) used cancer mortality rates, not incidence, as the basis for comparison. Comber et al. (28) admitted that they made assumptions regarding the fluoridation status of some of their subjects because public records were unavailable. Comber et al. (28) and Levy and Leclerc (29) noted that their study may have not included enough cases of osteosarcoma to show an association with fluoride intake. Other sources of
fluoride were not accounted for in these two studies. Levy and Leclerc (29) mentioned further that their methods did not assess whether osteosarcoma patients were receiving fluoridated water. These methodological issues make it difficult to generalize the results of any of these studies individually. However, when taken together it can be stated that no clear connection has been established between the concentration of fluoride in drinking water and the incidence of cancer. The scant positive associations found in the research are most likely due to other factors not controlled for by the research. After all, it is unlikely that bladder cancer risk would increase with fluoride ingestion, but not renal cancer (26, 27). Likewise, it is unlikely that oral and rectal cancer rates would be increased, but not rates of cancer of the stomach or intestine (28).

Conclusions and Implications

The fluoridation of public water supplies was an important factor in improving oral health worldwide in the 20th century. Research has shown fluoridation to be an effective means of reducing the prevalence of dental caries. The risk of fluorosis increases with the concentration of fluoride in drinking water. Fluoridation may offer a small enhancement of bone density during growth, but does not reduce fracture rates among older citizens. A clinically relevant increase in fracture risk for men related to fluoridation is currently unconfirmed. There is currently no conclusive evidence that increased fluoride exposure increases the risk of cancer.

Although the efficacy and safety of fluoridation is established by research, socio-economic status, access to dental care, and proper use of fluoride containing oral health products are also strongly associated with the risk of dental decay. It may no longer be appropriate, then, to use systemic fluoridation as a panacea for oral health care. Promoting both awareness of good oral hygiene practices and access to dental care in areas of low socioeconomic status should be public health priorities. The expansion or cessation of fluoride should be conducted with consideration for the availability of other means of caries control and not as a matter of course.

Nutrition professionals should work to educate individuals and the public that fluoridation of municipal water is not dangerous, but it does not mitigate the importance of good oral hygiene. Further,
utilization of available dental care should be encouraged. Minimizing dental exposure to fermentable carbohydrates (such as table sugar) should be a priority also. These interventions can help control dental caries in the population regardless of fluoridation status.
References


