

## Finding #1 – The Effectiveness of Drinking Water Fluoridation in Preventing Caries

### Historical Perspective

In 1901, a Colorado Springs dentist recognized that his patients with teeth with a brown stain or mottled dental enamel also had a very low prevalence of cavities (also called caries) (Centers for Disease Control and Prevention [CDC], 1999b). At this time in history, extensive dental caries were common, so this observation and its subsequent correlation with high amounts of fluoride ion in the water supply (2.0 - 12.0 milligrams per liter, mg/L) proved to be significant. Another dentist, H.T. Dean, DDS., took this information and conducted a survey of dental caries in relation to natural concentrations of fluoride in drinking water of 21 U.S. cities (Committee to Coordinate Environmental Health and Related Programs, USPHS [USPHS], 1991 pp.18-19; CDC, 1999a, p. 934). Dean observed that at a concentration of 1 mg/L, fluoride would significantly reduce caries while causing a low incidence of mottled enamel, now called fluorosis, of the mostly very mild type. Beginning in 1945 and 1946, community trials were conducted over 13-15 years in four pairs of cities in the U.S. and Canada. These studies found a 50-70% reduction of caries in children following addition of fluoride (in the form of sodium fluoride) to community water supplies at 1 mg/L. The incidence of mild fluorosis remained low (CDC, 1999a, p. 936). Some of the early studies were criticized for lacking appropriate controls, not applying randomization, and not controlling for potential examiner bias (Sutton, 1960). However, the large effect sizes in these trials, along with replication of these findings in subsequent studies, led to the acceptance of community water fluoridation as a public health approach to caries prevention.

Since those early times, community water fluoridation and the use of fluoridated water in the production of foods and beverages have become widespread. Beverages and foods prepared with fluoridated water contain fluoride. When these processed products are transported to nonfluoridated communities for sale, people consume them and ingest fluoride (Lewis & Banting, 1994, p. 156). People also travel across “fluoridation boundaries” to work or to attend school. This has been called the “halo” or “diffusion effect” and accounts for some of the narrowing difference in fluoride intake between fluoridated and nonfluoridated communities (CDC, 2001b, p. 9). A “reverse diffusion effect” also occurs, in which products from fluoride-deficient communities are ingested by people living in fluoridated areas. This has the same leveling effect when caries rates between fluoridated and nonfluoridated communities are compared (Ripa, 1993, p. 23).

Another trend that has contributed to a lowering of caries rates in both fluoridated and nonfluoridated communities has been the successive introduction of readily available fluoride products since the 1950s, including topical gels, fluoridated toothpaste, fluoride supplements and mouth rinses (Ripa, 1993, p. 23). With the introduction of fluoridated toothpaste in 1965 (at 1100 mg/L), the use of fluoridated dental products has become widespread. Between 1972 and 1983, fluoridated toothpaste sales in the U.S. market increased from about 70% to more than 95% (Driscoll, et al., 1986, pp. 50-51).

The level of dental decay in a population is typically summarized by measures of its *distribution* and its *severity*. Prevalence of caries—the percent of the population with any caries—is the most widely used measure of *distribution*. *Severity* of dental decay is measured as the mean number of decayed, missing and filled teeth (abbreviated “dmft” for primary teeth or baby teeth and “DMFT” for permanent teeth) or the mean number of decayed, missing or filled surfaces (abbreviated “dmfs” for primary tooth surfaces and “DMFS” for permanent tooth surfaces).

As a consequence of many factors, including fluoridation of public water supplies, almost universal use of fluoride products, and improved oral health behaviors, there has been a reduction in caries levels in the U.S. and many other established market economies since the 1970s. As shown in Table 1 (Featherstone,

1999, p. 32), national surveys of decay in children demonstrated dramatic decreases in both prevalence and severity in the 1970s and 1980s. Recent smaller surveys indicate that the decline in caries may have stalled since then (Featherstone, 1999, p. 31). The current national survey, NHANES IV, began collecting measures of dental caries, sealant use and enamel fluorosis in 1999. This survey will help determine whether or not caries rates in the U.S. have stabilized or continued to fall (<http://www.cdc.gov/nchs/nhanes.htm>).

Table 1  
*Mean DMFS and % Caries Free in Four U.S. Surveys*

Age Range		NCHS * 1971-74	NIDR ** 1979-80	NIDR ** 1986-87	NHANES III ♦ 1988-91
5-11	DMFS	3.0	2.0	1.2	.9
	% caries free	44%	58%	70%	74%
12-17	DMFS	10.4	6.8	4.7	4.4
	% caries free	10%	17%	27%	33%

(adapted from Featherstone, 1999, p 32)

\* NCHS – National Center for Health Statistics

\*\* NIDR – National Institute for Dental Research

♦ National Health and Nutrition Examination Survey

The extent of water fluoridation in a region determines the magnitude of the diffusion effect. This was evident in the 1986-87 National Institute of Dental Research (NIDR) survey of school children. The Midwest region had the highest percentage of the population having water fluoridation (72%) and the lowest difference in mean or average caries scores (-5.6%) among the seven U.S. regions, while the Pacific region had the lowest water fluoridation coverage (18%) and the highest difference in mean caries scores (61%) (Ripa, 1993, p. 23). In Region V (Texas, Oklahoma, New Mexico, and Colorado) 57% of persons was living in fluoridated communities and an 8% difference in average caries scores were found. The 1986-87 NIDR survey is the most recent and geographically relevant data the Fluoride Technical Study Group (FTSG) found to estimate caries levels in the Fort Collins area.

Even though overall decay rates on all tooth surfaces have fallen dramatically in children, caries continue to be an important public health problem. However, the distribution of the problem has changed over the past two decades. First, the distribution of decay among children has become skewed, with one quarter of children accounting for 80% of the caries experience in permanent teeth in the U.S. (Kaste, et al., 1996). According to the Centers for Disease Control and Prevention:

“Lower-income, Mexican American and African-American children and adults have more untreated decayed teeth than their higher-income or non-Hispanic white counterparts (4,5,8,9). Among low-income children, approximately one-third have untreated caries in primary teeth that could be associated with pain, difficulty in eating, and underweight (9)” (CDC, 2001a, p.2).

Second, the distribution of caries in the mouth has changed. Fluoride and brushing are both less effective in preventing caries on pit-and-fissure surfaces (the chewing surfaces) of teeth, leading to lesser reductions in caries on these surfaces than on the smooth tooth surfaces (U.S. Department of Health and Human Services [USDHHS, ]2000, p. 38). The width of most pits and fissures is smaller than a toothbrush bristle, making cleaning of their deep recesses almost impossible. The debris that accumulates forms a mechanical barrier that is thought to impede the flow of topical fluoride to these recesses. According to national surveys, the majority of all dental caries in school-age children now occurs on pit and fissure surfaces (Kaste et al., 1996 ; USDHHS, p. 166).

Finally, there has been a shift in the burden of caries from children to adults, due to the fact that tooth retention has increased among older adults over the past several decades (CDC, 2001b, p. 11). Gingival tissues tend to recede over time, exposing the tooth root to cariogenic bacteria that can cause root caries.

The latest national survey, the 1988-91 NHANES III, found that only 7% of adults with teeth were caries free. Figure 1 shows the marked increase in caries experience with age.

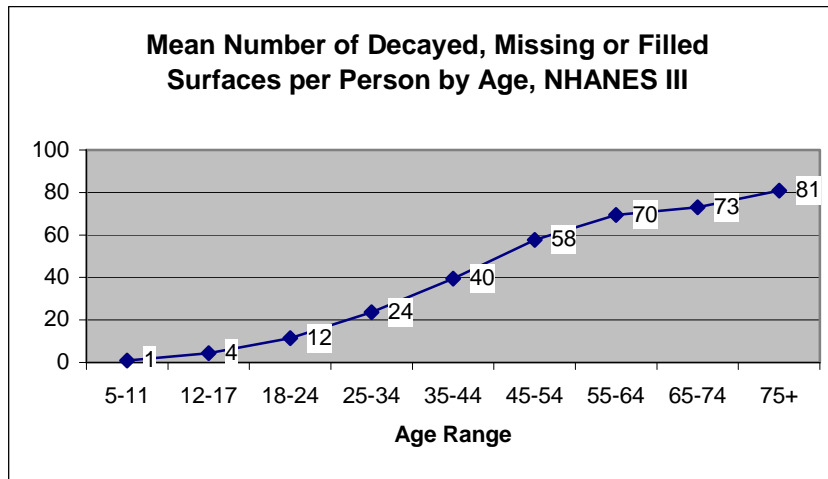


Figure 1. Mean caries levels by age, U.S., 1988-91

The first questions that the FTSG addressed were, “What is the effectiveness of community water fluoridation in preventing caries?” and “Is there an effect over and above that of fluoride in toothpaste and other dental products and processed foods and beverages?”

## How Fluoride Works

The main benefit of fluoride is that it inhibits dental decay. The basic process of decay begins in the bacteria-rich coating of the teeth called plaque (Featherstone, 1999, p. 32). Certain bacteria produce acids when they digest fermentable carbohydrates such as sugars and cooked starch. These acids can dissolve the calcium phosphate mineral of the enamel or dentin resulting in a carious or “white spot” lesion—a process called demineralization. The process of demineralization occurs each time carbohydrates are taken into the mouth. If not halted or reversed, the carious lesion progresses and a cavity is formed. If fluoride is present in the saliva and plaque fluid at the time bacteria is producing acid, it diffuses into the crystal surface with the acid and inhibits demineralization. Fluoride also enhances remineralization if a carious lesion begins to form and the remineralized surface is then more resistant to caries. Fluoride also interferes with the production of acid and adhesion by bacteria—whether this reduces the caries producing potential of bacteria is unclear (CDC, 2001b, p. 3).

Early theories about how fluoride worked held that it needed to be incorporated into developing enamel before the tooth erupted or emerged from the gums (CDC, 2001a, p. 4). Therefore, it needed to be swallowed by infants and children in order to reduce risk of caries. However, according to recent reviews, laboratory and epidemiological research over the past two decades indicates that fluoride’s predominant effect is post-eruptive and topical and therefore of benefit to adults as well as children (CDC, 2001b, p. 4; Featherstone, 1999; Locker, 1999). Most of the benefits of water fluoridation appear to accrue the same way they do for toothpaste and other dental products—through frequent topical exposures.

“When fluoridated water is the main source of drinking water, a low concentration of fluoride is routinely introduced into the mouth. Some of this fluoride is taken up by dental plaque; some is transiently present in saliva, which serves as a reservoir for plaque fluoride; and some is loosely held on the enamel surfaces (76). Frequent consumption of fluoridated drinking water and beverages and food processed in fluoridated areas maintains the concentration of fluoride in the mouth” (CDC, 2001b, p. 9).

That does not mean that ingestion (swallowing) of fluoride does not contribute to caries prevention benefits. An analysis of data from the Netherlands estimated that, for 15 year olds, half of the reduction in caries attributable to fluoride exposure was due to pre-eruptive exposure and half due to post-eruptive exposure, and that the best protection is achieved if fluoridation is available from birth (Groeneveld, 1990; reviewed by Ripa, 1993, p. 26). The relative benefits of pre and post-eruptive fluoride have yet to be resolved.

The fact that water fluoridation's major benefit is topical, combined with the fact that potential adverse effects can only be caused by systemic absorption, was an important concern to the FTSG. However, evidence suggests that the pre-eruptive benefits of water fluoridation, although smaller, should not be overlooked.

## **Evidence of Effectiveness of Community Water Fluoridation**

### **The FTSG's Approach**

The potential effectiveness of exposure to fluoride in preventing and controlling caries can be evaluated from observation (epidemiologic studies) or experiment (randomized trials). With either approach, the researcher compares measures of caries among a group exposed to fluoride versus measures of caries in a concurrent or historical group that was not exposed or was less exposed. Randomized clinical trials (with concurrent controls, double blind design and placebos) are considered the gold standard of evidence for effectiveness of a clinical treatment. Such experiments have shown that fluoride delivered in toothpaste, mouthwash, gels, supplements and varnishes reduce caries (CDC, 2001b, pp. 20-21; USPHS, 1991, p. 27). However, it is not possible to conduct randomized controlled experiments to measure the effectiveness of adding fluoride to community water supplies. Study subjects (members of communities) can neither be randomly allocated to treatment and control groups, and it is difficult to blind examiners to whether or not study subjects are living in a fluoridated community (CDC, 2001b, p. 20). Therefore, evidence of the effectiveness of community water fluoridation must be based on observational studies. Since the researcher does not control the allocation of treatment in an observational study, there is a potential for the validity of such studies to be threatened by a variety of biases. Some study designs are more vulnerable than others. Furthermore, because background caries rates have dropped since the early community trials, and differences between exposed and non-exposed individuals have narrowed, biases introduced by weak study designs could be large enough to mask a true difference in caries measures or demonstrate a difference when one does not exist (Expert Panel for Water Fluoridation Review, City of Calgary, 1998, p. 23). Therefore it is critical that both the quantity of studies and their quality be considered in assessing the weight of evidence regarding the current effectiveness of community water fluoridation. A thorough assessment of the evidence requires a systematic approach to searching for and selecting studies to include and to assess their validity.

The FTSG's approach was to identify recently published comprehensive summaries of the evidence of water fluoridation effectiveness commissioned by health authorities, to evaluate how each review protected against biases (review quality), to highlight findings of reviews of high quality, and to use all reviews to identify areas of uncertainty. A subset of eight of the fluoride evidence reviews initially selected by the FTSG addressed the issue of the effectiveness of community water fluoridation. Descriptions of the approaches of each of these reviews to collecting and weighing the evidence regarding the benefits of community water fluoridation are found in Appendix 1. The FTSG identified five comprehensive reviews published since 1990 in which the review or research panel made an attempt to identify all relevant research and evaluate the threats to validity of individual studies. Four were commissioned by national health authorities and one by a provincial government. Two of the reviews specifically addressed the question of whether the effectiveness of water fluoridation remains significant in the current context of lower mean caries levels and widespread exposure to other sources of fluoride (National Health Service Centre for Reviews and Dissemination, University of York [NHS], 2000; Locker, 1999).

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(76) Reference within a quote is available in the source document.

The FTSG first reviewed the four nationally commissioned studies and their findings. The group then described evidence of the declining magnitude of effectiveness in recent times. Finally, the FTSG examined several recently conducted epidemiological studies in which no caries benefit was found to ascertain why this might be.

### **What Recent Comprehensive Reviews Found**

In 1991, the Ad Hoc Subcommittee on Fluoride convened by The U.S. Department of Health and Human Services and the United States Public Health Service (USPHS) published their comprehensive review and evaluation of the public health benefits and risks of fluoride in drinking water (USPHS, 1991). Using the traditional epidemiological criteria for establishing causation, the Subcommittee found:

“The reduction in dental caries among persons exposed to fluorides fulfills all the criteria for a causal relationship: an association was found with a dose-response effect, the findings were replicated under a great variety of circumstances by different investigators, alternative explanations and observer bias have been excluded, the findings are biologically plausible, and the effect, prevention of dental caries, continues to show that the fluoridation of water supplies substantially reduces the scores of dental caries. The decline over time in difference in caries scores between fluoridated and non-fluoridated areas is due in part to the increased availability of fluorides in non-fluoridated areas, as in toothpaste and other vehicles for fluorides” (USPHS, 1991, p. 35).

The Subcommittee did not use explicit criteria for assessing the quality of studies, instead addressing threats to validity by examining and excluding alternative explanations for study results (USPHS, 1991, pp. 26-28).

In 2000, a systematic review of the literature on the effectiveness of fluoridation conducted for the British National Health Services by the Center for Reviews and Dissemination at the University of York published their results. The independent panel of experts established explicit search and selection criteria for inclusion of research on community water fluoridation conducted between 1966 and February 2000 in industrialized countries. The review included only studies presenting both baseline and follow-up data on child caries per tooth (DMFT) in two communities with different levels of fluoride in drinking water. A total of 26 studies on the effect of water fluoridation on caries rates were found that met their minimum design standards, five of them unpublished. Only one examined adults. Based on these 26 studies completed between 1951 and 2000, they found sufficient evidence of moderate quality to conclude “fluoridation of drinking water supplies does reduce caries prevalence” (NHS, 2000, p. 23). This amounted to a (median) 14.6% increase in children without caries (range -5.0% to 64%) or a median 2.25 (range 0.5 to 4.4) fewer teeth per mouth having caries (McDonagh, et al., 2000). The evidence included both studies that compared fluoridated and nonfluoridated communities (30 measures) as well as studies that compared never fluoridated or still fluoridated communities with communities that stopped fluoridating the water supply (22 measures). “The best available evidence from studies following withdrawal of water fluoridation indicates that caries prevalence increases, approaching the level of the low fluoride group” (NHS, 2000, p. xii). The quality of evidence for this finding was rated as “of moderate quality” by the research panel.

The Fluoride Recommendations Work Group was assembled by the U.S. Centers for Disease Control and Prevention (CDC) in the late 1990s to develop recommendations for using fluoride to prevent and control caries. In 2001, they came to the following consensus regarding the current effectiveness of water fluoridation in preventing decay in children:

“Initial studies of community water fluoridation demonstrated that reductions in childhood dental caries attributable to fluoridation were approximately 50-60%. More recent estimates are lower, 18-40%. This decrease in attributable benefit is likely caused by the increasing use of fluoride from other sources, with the widespread use of fluoride toothpaste probably the most important.

The diffusion or “halo” effect of beverages and food processed in fluoridated areas, but consumed in non-fluoridated areas also indirectly spreads benefits of fluoridated water to non-fluoridated communities. This effect lessens the differences in caries experience among communities” (CDC, 2001b, p. 11).

The group noted that quantifying the benefits of water fluoridation in adults is more complicated, but found evidence to support effectiveness in this group as well (CDC, 2001b, p. 11). Using a system developed to assess the quality of evidence regarding clinical preventive services (U.S. Preventive Services Task Force, 1996), the group rated the evidence as II, on a scale from I (randomized controlled trials which are considered the highest quality) to III (the lowest level as in the opinions of experts).

The Task Force on Community Preventive Services, a 15-member independent expert panel supported by the CDC, the U. S. Department of Health and Human Services and other federal and public/private partners, published the results of its systematic review of the evidence of effectiveness of selected population-based interventions to prevent and control dental caries in 2001 (CDC, 2001a, p. 8). Similar to the British National Health Services panel, the group sought to review and evaluate all research on community water fluoridation conducted between 1966 and December 2000 in the U.S. and other industrialized countries. The process yielded 21 studies that met validity criteria. The median decrease in dental caries upon starting or continuing community water fluoridation among the highest quality studies was 29.1% (21 measures, range 110.5% decrease to 66.8% increase). The median increase in caries following cessation of water fluoridation in the three qualifying studies was 17.9% (five measures, range 42.2% decrease to 31.7% increase). Two of the nine studies in the highest quality group showed negative results (did not show an increase in caries after cessation of fluoridation). Reviewers concluded, “These inconsistent estimates of effectiveness appear to have resulted from inadequate control of confounding due to notably lower baseline caries prevalence in fluoridated compared with non-fluoridated areas” (Truman, et al., 2002, p. 27). Based on this review, the Task Force made the following recommendation, “Based on the evidence of effectiveness, the Taskforce strongly recommended community water fluoridation” (CDC, 2001a, p. 7).

## **Evidence of the Current Magnitude of Effectiveness**

Over the last 30 years, the overall prevalence of caries has decreased dramatically (Table 1). All the reviews above noted that the declining levels of caries in the U.S. and elsewhere translate into smaller net differences in mean caries levels between fluoridated and nonfluoridated communities. The second component of the effectiveness question the FTSG raised was, “What is the magnitude of caries protection from water fluoridation in the current setting of widespread availability of other sources of fluoride?”

Comparing the summary estimates of effectiveness from a series of sequential comprehensive literature reviews demonstrates the shrinking differences attributable to water fluoridation. In 1982, Murray and Rugg-Gunn (1982) reviewed 95 water fluoridation studies conducted in 20 countries between 1945 and 1978. They found evidence that fluoridation reduced caries by 40-50% for primary teeth and 50-60% for permanent teeth in this period (Murray & Rugg-Gunn, 1982). In 1989, Newbrun (1989) reviewed the world literature from 1976 to 1987. He found 30-60% reductions in primary teeth and 30-40% reductions in permanent teeth in adolescents and adults during this period. Figure 2 shows the decrease in mean caries prevalence from 1979-80 to 1986-87 in eight and fifteen year olds from a national sample of school children conducted by the NIDR. The mean percent reductions in caries rates between continuous residents of fluoridated and nonfluoridated communities is also demonstrated (Brunelle & Carlos, 1990; Brunelle & Carlos, 1982).

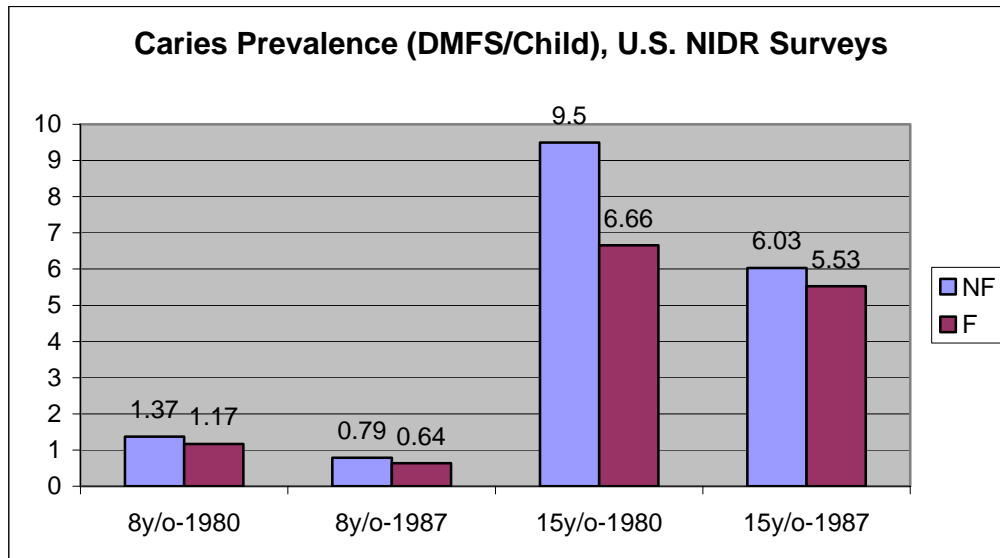


Figure 2. Decrease in mean caries prevalence from 1979-80 to 1986-87 in eight and fifteen year olds

Lewis and Banting (1994) began with Newbrun’s review and updated it through 1992. They showed that although the overall mean percent reductions between the years 1977-82 and 1983-91 were similar (27% and 25% respectively), the absolute mean difference between fluoridated and nonfluoridated communities in number of surfaces with caries dropped from 1.61 to 0.73 between these periods (Lewis & Banting). They pointed out the sharp contrast between these results and the original community trials where differences of about ten surfaces (five DMFTs) were seen in adolescents. The authors suggested that since the diffusion of fluoride into nonfluoridated communities is impossible to control for, the effectiveness of water fluoridation could no longer be determined (Lewis & Banting).

Two recent reviews specifically addressed the question of the current magnitude of effectiveness. First, Dr. David Locker of University of Toronto conducted a systematic literature review of the effectiveness of community water fluoridation spanning 1994 through November 1999, for the Public Health Branch, Ontario Ministry of Health & First Nations and Inuit Health Branch, Health Canada. Twenty-nine published studies were found in which optimally fluoridated communities were compared with concurrent or historical controls (Locker, 1999). Twenty-five were weak “before-after” ecological study designs—four were more robust cross-sectional studies. They examined the magnitude of the current caries prevention effect using two of the more robust studies, both cross-sectional; one based on the 1986-87 National Survey of U.S. School Children and the other from Australia. While the U.S. study found water fluoridation reduced caries by 25%, the absolute difference in mean caries prevalence between those living in fluoridated and those living in nonfluoridated communities was 1.14 surfaces in deciduous (baby) teeth and 0.55 surfaces in permanent teeth (Heller, Eklund, & Burt, 1997). In South Australia, the differences were smaller, ranging from 0.12 to 0.3 surfaces in permanent teeth (Slade, Davies, Spencer, & Stewart, 1995). The reviewers concluded that caries reductions are now relatively small in absolute terms, particularly in permanent teeth and that water fluoridation explains only a small part of the variation in caries experience between children. The authors concluded:

“Given the weaknesses in design and the methodological flaws to which many of the studies were subject, the data from these more recent studies must be treated with some caution. While the balance of evidence overall suggests that water fluoridation does reduce caries experience, the magnitude of the effect is subject to a degree of uncertainty but is unlikely to be large in absolute terms” (Locker, 1999, p. 33).

The NHS Center for Reviews and Dissemination (2000) analyzed studies conducted since 1974 to examine the effect of water fluoridation over and above other sources of fluoride. Of the ten studies that met their inclusion criteria, seven examined the discontinuation of fluoride. Although two of these studies (Kunzel & Fischer, 1997; Maupome, Clark, Levy, & Berkowitz, 2001) found that mean levels of caries did not increase after the fluoridated community stopped fluoridating, the remainder showed that there was a greater increase in caries levels in the fluoridated-ended communities than in the controls. The panel concluded, “a beneficial effect of water fluoridation was still evident despite an assumed exposure to non-water fluoride in the populations studied” (NHS, 2000, p. xii). The quality of evidence for this finding was rated as “of moderate quality” by the research panel.

The Medical Research Council of the British Health Service established a Working Group to consider what further research is needed to improve knowledge about water fluoridation and health, following the release of the NHS review. The Working Group report published in September 2002 specifically recommended more research of the effects of water fluoridation against a background of widespread use of fluoride toothpaste, while controlling for age, social class, ethnic group, sugar consumption and use of other discretionary fluorides.

## **Studies of the Effectiveness of Community Water Fluoridation in Adults**

Locker also reviewed recent studies of effectiveness of community water fluoridation in adults (Locker, 1999, p. 31). Four studies published since 1990 met inclusion criteria. All four studies found substantial reductions in coronal and root caries in adults living in fluoridated as compared with nonfluoridated communities. Two of the studies had prospective cohort designs (a design with fewer threats to validity). Grembowski, Fiset and Spadafora (1992) tracked caries rates in 972 Washington state employees and spouses, aged 20 to 34 years, in two fluoridated communities and a nonfluoridated community. After controlling for an extensive array of variables, they found that drinking water fluoridation reduced DMFS by 0.35 surfaces per year of fluoridation exposure (Grembowski, et al.). For 18 months, Hunt, Eldredge and Beck (1989) prospectively followed seniors who were long-term residents of fluoridated and nonfluoridated communities. They found that the risk of developing caries was 20% less on the crowns of teeth and 27% less on root surfaces in those with long-term residence in fluoridated communities (Hunt, et al.).

Considering that the population is aging, that tooth retention has increased in adults in recent decades (CDC, 2001b, p. 11), and that root surface exposure due to gingival recession renders adults particularly susceptible to root caries, the question of the effectiveness of water fluoridation in prevention of caries in adults is particularly important. The small number of studies examining this population, while consistent, cannot provide robust proof of effectiveness. In addition to Locker, the CDC, the U.S. Task Force for Community Preventive Services, and the British Medical Review Council (see below) all identified this as an area where future research should be focused (Locker, 1999; CDC, 2001a; Truman et al., 2002; Medical Research Council [MRC], 2002).

## **Fluoridation-Ended Sites in Which No Caries Increases Were Found**

While virtually all studies examining the initiation of fluoridation demonstrate caries reductions compared to nonfluoridated communities, recent studies in which the impact of ending fluoridation has been measured have yielded mixed results. The NHS review and the review by the Task Force of Community Preventive Services both examined this evidence and concluded that mean caries rates generally increase when fluoridation is stopped. The Task Force review estimated the relative increase at 17.9% based on the highest quality studies (CDC, 2001a). However each review included examples of communities in which caries rates did not increase. Studies demonstrating these inconsistent results are frequently cited by opponents of fluoridation. For this reason, and because the impact of stopping fluoridation is of particular interest to the current policy question in Fort Collins, the FTSG chose to examine these studies in detail.

Among the 14 recent studies (completed after 1985) in which water fluoridation was discontinued, nine showed an increase in caries rates. Five found that caries levels had either remained stable or dropped after fluoridation ended. To the extent that these study settings are generalizable to Fort Collins, it is important to determine whether or not their results can be explained. If explanations are wanting, they raise the level of uncertainty of the FTSG's findings. A brief review of each of these studies follows.

Two ecological time-series studies published in 1997 and 2000 found that caries prevalence among children decreased in four fluoridation-ended sites in former East Germany (Kunzel & Fischer 1997; Kunzel, Fischer, Lorenz, & Bruhmann, 2000). In these four industrial towns, systematic surveys of caries prevalence in children have been conducted every two to four years since fluoridation began (1959-1972). During the first three decades of these surveys, the level of caries prevalence was strictly correlated with the availability of an optimal fluoride concentration in the drinking water. Water fluoridation was followed by a decrease of caries, and interruptions in fluoridation were followed by increasing caries levels. A different trend was noted in the 1990s. Contrary to an expected caries increase there was a consistent statistically significant decrease across virtually all ages (ages 6-15) in surveys of life-long residents conducted three to eight years after cessation of fluoridation. These two studies raise important questions, but both have serious design flaws. First, the authors note that the reunification in Germany in 1990 led to "dramatic social transformation," including not only cessation of water fluoridation, but also "complete change" in provision of preventive dental care and oral health services. Dental services and school dental services were largely privatized (though coverage remained comprehensive), dentist utilization increased, fissure sealants were introduced, fluoridated salt was introduced, use of fluoridated toothpastes increased from 15% to 88%, use of topical fluorides and antibiotics increased and sugar consumption decreased, all within several years (Kunzel, Fischer, Lorenz, & Bruhmann). Because the design of the 1997 study was ecological, the authors were not able to control for these important intervening factors. In the 2000 study, some of these factors were measured in individual subjects, but there was no concurrent control community, so the net impact could not be estimated. Both studies were also flawed by changes in methods of subject selection before and after cessation of fluoridation, lack of blinding, and measurement issues. The authors conclude:

"The causes for the changed caries trend were seen on the one hand in improvements in attitudes towards oral health behavior and, on the other hand, to the broader availability and application of preventive measures (F-salt, F-toothpastes, fissure sealants etc.). There is, however, still no definitive explanation for the current pattern and further analysis of future caries trends in the formerly fluoridated towns would therefore seem to be necessary" (Kunzel, Fischer, Lorenz, & Bruhmann, 2000, p. 382).

Further corroboration of this apparent phenomenon was noted in a two-community ecological before-after study of caries in 6-15 year olds conducted in Finland (Seppa, Karkkainen, & Hausen, 1998). The city of Kuopio was fluoridated (1.0 mg/L) in 1959 and discontinued the practice in 1992. The comparison town of Jyvaskyla was not fluoridated (0.1 mg/L). The percentage of children using fluoridated toothpaste was 85% in both towns. "In 1995, a decline in caries was seen in the two older age groups in this nonfluoridated town. In spite of discontinued water fluoridation, no indication of increasing trend of caries could be found in Kuopio" (Seppa et al., p. 256). However, once Kuopio stopped fluoridating there was a *slower decline* in caries so that by three years post-fluoridation the relative advantage of Kuopio over Jyvaskyla in terms of caries rates had disappeared. This was in spite of more frequent use of other fluoride measures, including fluoride tablets in Kuopio (Seppa, p. 261). It is important to note that Finland has comprehensive prevention-oriented dental services for all children and adolescents, and the use of fluoride toothpaste, varnishes and tablets are common.

La Salud, Cuba was fluoridated in 1973. Water fluoridation at 0.8 mg/L ceased in 1990. "Toothbrushes were scarce, F-toothpastes were not available, and the sugar consumption was high" (Kunzel & Fischer, 2000), yet, in 1997 there was a significant decrease in caries levels in the oldest age group (12 and 13 yr.

olds) and levels in the younger ages remained stable. This before-after survey had no control group so no distinction can be made between what was due to secular trends and what was due to cessation of fluoridation. Perhaps most important, a fluoride mouth rinsing program was initiated in the schools of La Salud soon after cessation of water fluoridation (Kunzel & Fischer, 2000).

A study conducted in two communities in British Columbia, a fluoridated-ended and a still fluoridated site, included both a time-series analysis and a prospective cohort analysis of 8-11 and 14-17 year old children at 1½ and 3½ years after the study community stopped fluoridating in 1992 (Maupome, Clark, Levy, & Berkowitz, 2001; Maupome, Shulman, Clark, Levy, & Berkowitz, 2001). The prevalence study found that while caries rates stayed the same in the still fluoridated community, they dropped significantly in the fluoridated-ended community over the three years. However, overall caries prevalence rates in 8 and 11 year olds were still 52% and 35% lower in the still fluoridated community in the final survey. Caries incidence rates (new cases) were also 20% lower in the still fluoridated community. This suggested that confounding by other factors might account for this unexpected drop in caries. After adjusting for socio-economic status, age, frequency of mouth washing and tooth brushing with fluoridated products, exposure to fluoride supplements and overall snacking practices, the researchers noted higher caries scores for at-risk surfaces (erupted and unsealed surfaces) in the fluoridation-ended group. The researchers also tracked progression and reversal of “white spots,” the surface lesions that lead to cavities. Comparing children/adolescents in the two communities, the odds were more than two times greater (odds ratio was 2.42, 95% confidence interval was 1.97-2.98) that an early smooth surface “white spot” would progress to a cavity in the fluoridation-ended community than in the still fluoridated community (Maupome, & Shulman, et al., 2001). The researchers noted that, together with increasing use of sealants in both communities, there appeared to be earlier and more common fillings applied in the fluoridation-ended site, and that this might account for reductions in active caries in both communities. This study demonstrates the complicated shifts in caries and caries treatment experience following cessation of fluoridation in a relatively affluent community with low baseline caries risk. Like the studies above, caries prevalence decreased over time in the fluoridation-ended site, yet in this well designed study, the researchers found that the risk of caries progression was greater once other factors were controlled for.

In spite of their respective design flaws, these five studies raise important issues: First, there are multiple factors that determine caries incidence in a community. In some contexts, community water fluoridation’s contribution to caries prevention and reversal is over-shadowed by other factors such as wide-spread use of fluoridated toothpaste combined with a high standard of living, universal access to dental care, or school-based prevention programs. When fluoridation was stopped in these contexts, mean caries levels did not increase, though individuals who did not receive enough fluoride may have suffered. Second, the act of suspending water fluoridation may provide the impetus to change personal oral health behaviors or to initiate other public oral health programs, as it did in each of these settings. These changes can prevent expected increases in caries. Third, differences in caries rates between exposed and non-exposed individuals have narrowed to the point where biases introduced by weak study designs could be large enough to mask a true difference in caries measures or demonstrate a difference when one doesn’t exist. Fourth, there may be other factors, as yet unidentified, that contributed to caries rates not increasing after stopping water fluoridation in these cities.

Perhaps the most important difference between the settings reviewed and those in Fort Collins (and the U.S. as a whole) is the lack of universal access to dental care and the lack of substantive school-based prevention programs locally (see Finding #3).

## **Gaps in Knowledge**

The Task Force for Community Preventive Services summarized the gaps in knowledge regarding community water fluoridation effectiveness in their 2002 review (Truman, et al., 2002, p. 32):

- “What is the effectiveness of laws, policies, and incentives to encourage communities to start or continue water fluoridation?”
- “What is the effectiveness of community water fluoridation in reducing socioeconomic or racial and ethnic disparities in caries burden?”
- “What is the effectiveness of community water fluoridation among adults (aged  $\geq 18$  years)?”
- “What, if any, are the effects of the increasing use of bottled water and in-home water filtration.”
- “How effective is community water fluoridation in preventing root-surface caries?”

The Medical Research Council added the need for more studies designed to estimate the impact of community water fluoridation in children ages 3-15 in today’s environment of widespread use of fluoride dentifrices (MRC 2002, p. 18). In reviewing the York Study, the Medical Research Council noted that:

“The York Review concluded that water fluoridation was effective, but the authors were reluctant to estimate the likely impact in today’s environment. Therefore, to inform policy, future research-including economic evaluation- should determine the short-term impacts of water fluoridation on dental caries (i.e. within four years of implementation), though there would be advantages in extending studies to ten years and beyond in order to capture more fully the effects on the permanent dentition” (MRC, 2002, p. 19).

A member of the FTSG raised a concern that exposure to water fluoridation may delay eruption of teeth and this could account for apparent effectiveness of caries prevention in children. The FTSG was not able to find credible evidence to support this concern.

### **FINDINGS: The Effectiveness of Drinking Water Fluoridation in Preventing Caries (Cavities)**

The weight of the evidence suggests that there is caries reduction in populations exposed to water fluoridation at or near an optimal level. The primary mode of action of fluoride in preventing caries (cavities) is its topical action on the surface of the teeth; systemic action from ingestion is now thought to play a minor role. This benefit amounts to a relative caries reduction of 25% and an absolute prevalence difference of 1.14 surfaces with caries in primary teeth and 0.5 surfaces with caries in permanent teeth in children according to the most recent U.S. surveys of schoolchildren. Among the four studies of caries prevention in adults, the most recent study showed that community water fluoridation reduced surfaces with caries by 0.35 surfaces per year of fluoride exposure. It appears that community water fluoridation is effective in all age groups in preventing dental caries. The benefit of drinking water fluoridation decreases as individuals in the population receive fluoride from other sources (e.g., toothpastes, dental care, etc.). Even with the limitations of some of the studies, there appears to be a net benefit in caries reduction from drinking water fluoridation over and above that from toothpaste and other sources of fluoride. Among the 14 recent studies (completed after 1985) reviewed in which water fluoridation was discontinued, nine showed an increase in caries rates. Five communities (all of them in other countries) that suspended water fluoridation did not find that caries rates increased. It is uncertain to what degree changes in oral health behaviors, introduction of new preventive programs and increased delivery of professional treatments in response to cessation of fluoridation can account for these findings. Since these studies were conducted in foreign communities in which there was socialized dental care and school-based oral health programs, their results may not apply to Fort Collins.

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