Fluorides in Dental Public Health Programs

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Dental caries is a chronic disease that affects a large proportion of the population in the United States. Although dental caries has declined in the United States, almost 28\% of 2- to 5-year-old children experience the disease [1]. Among 16- to 19-year-old children, the average number of decayed, missing, and filled surfaces (DMFS) is 5.8. Adults 40 to 59 years of age have an average of 42 DMFS. Dental diseases account for 30\% of all health care expenditures in children [2].

Theoretically, dental caries can be controlled by altering the bacterial flora in the mouth, modifying the diet, increasing the resistance of tooth to acid attack, or reversing the demineralization process. In practice, however, only the use of fluorides and sealants has been shown to be successful in reducing dental caries in populations [2]. Therefore, the development of interventions that employ fluorides to prevent dental caries has been a large part of the dental public health effort. Traditionally, dental public health has focused on the community as a whole instead of the individual patient, and targeted interventions and policies to improve the health of the community. This article reviews some of the ways fluorides are used in public health programs and discusses issues related to the effectiveness, cost, and policy of these uses.
Fluoride and dental health

Frederick McKay, a Colorado dentist, noticed that clusters of individuals had stained teeth, and he hypothesized that these stains were related to some agent in the drinking water [3]. Studies later identified the agent as the fluoride in water. During the epidemiologic investigations of the staining, H. T. Dean made the observation that children with mottled teeth seemed to have less tooth decay than those who did not have the mottling. Further studies clearly demonstrated the inverse association between the fluoride level in drinking water and the amount of tooth decay [4].

Four large-scale community studies were initiated in the period of 1945 to 1947 to assess whether adjusting the level of fluoride in drinking water to an optimal level could provide a beneficial caries-inhibiting effect. Water supplies in the communities of Grand Rapids, Michigan, Newburgh, New York, Evanston, Illinois, and Brantford, Ontario were adjusted, and this became the birth of fluoridation. The results obtained in these studies were compelling both because of the magnitude of the beneficial impact of fluoride on dental caries and because of the consistency observed across the studies [5]. Since the early studies of water fluoridation, different approaches have been investigated to deliver fluoride to the oral environment, as water fluoridation is not practical in every community. Table 1 shows fluoride levels and the frequency of its use in public health programs.

Mechanism of action of fluoride

The initial studies suggested that the beneficial effects of fluoride were a result of incorporation of fluoride into tooth crystals during its formation [6]. The early studies also showed that there were posteruptive benefits from

Table 1
Use of fluorides in public health programs

<table>
<thead>
<tr>
<th>Program</th>
<th>Fluoride (F) levels</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community water fluoridation</td>
<td>0.7 mg/L – 1.2 mg/L F</td>
<td>Daily</td>
</tr>
<tr>
<td>School-based fluoride rinse</td>
<td>10 mL or 5 mL 0.2% sodium fluoride (9 mg F per 10 mL)</td>
<td>Weekly</td>
</tr>
<tr>
<td>Fluoride tablet</td>
<td>0.25 mg to 1 mg F</td>
<td>Daily</td>
</tr>
<tr>
<td>Fluoride varnish</td>
<td>0.3 mL–0.5 mL 5% sodium fluoride per application 22,600 ppm (2.26% F)</td>
<td>3 to 6 month interval</td>
</tr>
<tr>
<td>Supervised tooth brushing</td>
<td>1,000 ppm–1,100 ppm (1 mg to 1.1 mg F/g)</td>
<td>Twice daily</td>
</tr>
<tr>
<td>Salt fluoridation</td>
<td>200 mg–250 mg F/kg salt</td>
<td>Daily</td>
</tr>
</tbody>
</table>

fluoridation [4–7]. This led to studies of topical effects of fluoride on the tooth surface. The laboratory studies suggest that the predominant action of fluoride is in the process of remineralization and inhibition of demineralization of enamel [8,9]. However, epidemiologic studies conducted in the 1950s, and more recent Australian studies, suggest important pre-eruptive benefits and support continuous exposure for the best outcome [5,7,10,11]. These investigators noted that a thin fluorapatite coating on the surface of hydroxyapatite crystals could lead to decreased solubility of enamel. Regardless of the predominant mechanism of action, water is an efficient vehicle for delivering a low concentration of fluoride at high frequency: that is, as it is consumed throughout the day.

Community water fluoridation

Fluoridation of community drinking water is the precise adjustment of the existing natural fluoride concentration in drinking water to a safe level that is recommended for caries prevention. The United States Public Health Service has established the optimum concentration for fluoride in the water in the range of 0.7 mg/L to 1.2 mg/L [12]. The optimum level for a region depends upon the annual average of the maximum daily air temperature. As of 2002, more than 170 million people in the United States, or 67% of those using public water supplies, drink water containing the recommended level of fluoride to prevent caries [13].

In the United States, 10 states have laws requiring communities to implement fluoridation if they meet certain conditions. In other states, the decision to fluoridate is usually made by individual communities. The water fluoridation program is usually administered under the supervision of state health and environmental agencies. Technical assistance is provided by the Division of Oral Health of the Centers for Disease Control and Prevention, whereas the Engineering and Administrative Recommendations for Water Fluoridation provides guidance for program administration [14].

Effectiveness of fluoridation

Early studies of water fluoridation suggested caries reductions in the range of 50% to 70% in children [15]. To test the relative effectiveness and cost of various interventions under modern conditions, the Robert Wood Johnson Foundation supported a large-scale study of school children in 10 different cities. This study showed that water fluoridation was the most cost-effective means of reducing tooth decay in children [16]. Fig. 1 compares the 4-year mean increment in caries between fluoridated and nonfluoridated communities among cohorts of fifth grade children that received class room and clinic interventions, and the cohort of longitudinal control groups receiving no intervention in fluoridated and nonfluoridated communities. Several recent authoritative reviews conducted in the United
States, Australia, United Kingdom, and Ireland provide further evidence of the effectiveness of water fluoridation under conditions in which there is widespread exposure to fluoride from sources other than drinking water, such as fluoridated toothpastes and bottled beverages manufactured with fluoridated water [17–20]. The National Health Center for Reviews and Dissemination, University of York, concluded that the best available evidence suggested that fluoridation of drinking water supplies reduced dental caries prevalence, both as measured by the proportion of children who are caries-free and by the mean change in decayed, missing, and filled teeth score [17]. An independent Task Force convened by the Centers for Disease Control and Prevention that developed the Guide to Community Preventive Services, found strong evidence that water fluoridation is effective in reducing the cumulative caries experience in the population [18]. The Task Force computed estimates of effectiveness based on three groups of studies. In studies examining the before and after measurements of caries at the tooth level, starting or continuing fluoridation decreased dental caries experience among children aged 4 to 17 years by a median of 29.1% during 3 to 12 years of follow-up. In studies that examined only post exposure measurements of caries at the tooth level, starting or continuing fluoridation decreased dental caries experience among children aged 4 to 17 years by a median of 50.7% during 3 to 12 years of follow-up.

Fig. 1 shows several recent reports in the United States. The difference in dental caries between fluoridated and nonfluoridated communities is still noticeable, despite the ubiquitous presence of fluoride in food, water, and dental products [21–26]. Additional supportive evidence comes from studies conducted in Australia and Ireland [27–31].

In a United States national survey, the mean DMFS of 5- to 17-year-old children with continuous residence in fluoridated areas under modern
conditions of fluoride exposure was about 18% lower than in those with no exposure to fluoridation [32]. The availability of other forms of fluoride and the diffusion of fluoride through beverages and foods processed in fluoridated communities are thought to provide an explanation for the diminished difference in caries observed in recent years between fluoridated and nonfluoridated communities [32,33]. For example, children living in nonfluoridated areas in states such as Ohio, with more than 90% fluoridated areas, are more likely to receive the indirect benefit of water fluoridation through a diffusion effect (high diffusion) than that of in a state like New Jersey, where the fluoridation penetration is lower (low diffusion). According to Griffin and colleagues [34], on average, 12-year-old girls living in nonfluoridated areas with the least amount of exposure to a diffused effect experienced 1.44 more DMFS than did similar children residing in fluoridated communities. The indirect benefit of fluoridation, as evidenced by a comparison between children living in nonfluoridated communities with a high amount of fluoride exposure through diffusion and children living in nonfluoridated areas with the least amount of exposure to diffused effect, was an average of 1.09 fewer DMFS [33].

Cost effectiveness and cost savings

The National Preventive Dentistry Demonstration Program (NPDDP) reported that the reductions in decay attributable to water fluoridation were almost the same as those obtained with sealants [16]. These investigators estimated the costs of maintaining a child in a sealant program to be $23 per year, while the annual per capita cost of water fluoridation is substantially lower. Many factors, such as equipment, installation, chemicals, and labor, affect the cost of fluoridating a community [35]. The size of the
community is a major determinant. According to the *Guide to Community Preventive Services*, the estimated median cost per person per year in the United States ranged from $2.70 for systems serving fewer than or equal to 5,000 people, to $0.40 for systems serving greater than or equal to 20,000 people [18].

Fluoridation has been shown to be cost saving. In 2001, Griffin and colleagues [35] estimated that for every one dollar expended, fluoridation saved $38 in treatment costs. Using similar methods, O’Connell and colleagues [36] estimated that the fluoridation program in Colorado was associated with an annual savings of $148.9 million (range, $115.1 to $187.2 million) in 2003, or an average of approximately $61 per person.

**School-based fluoride mouth rinse programs**

Fluoride mouth rinses were developed in the 1960s as an alternative to professional applications of gels and other topical fluoride products in school settings. With the availability of fluoridated water and fluoride containing toothpastes, these programs are now targeted to high-risk schools in nonfluoridated areas.

Typically, schools are provided with a year’s supply of mouth rinse that consists of unit doses of 0.2% neutral sodium fluoride solutions in 5-mL or 10-mL pouches, along with cups and napkins. Children in grades one through six participate after obtaining written permission from parents. The procedure consists of vigorously rinsing with 5 mL or 10 mL of solution for 60 seconds on a weekly basis in the classroom under the supervision of a teacher, nurse, or a dental hygienist. After the rinsing, the fluoride solution is expectorated into a cup, a napkin is inserted into the cup to absorb the solution, and both are disposed. Younger children are provided with only 5 mL of solution. Fluoride mouth rinse programs are not recommended for preschool children in the United States, as some children may swallow the solution intended for topical application.

There are several advantages with the school-based fluoride rinse program. Generally, compliance is better because children perform the procedure as a group activity under supervision. Children tend to complain less about the taste when compared with that of topical fluorides. Because fluoride rinses are generally administered by volunteers, the cost per child is less when compared with that of professionally applied topical fluorides. However, the program requires trained personnel, a supervising dentist or registered dental hygienist, physician or nurse practitioner, and cooperation from teachers and school authorities.

**Effectiveness**

School-based fluoride mouth rinse programs have been the subject of numerous reviews [2,37,38]. A 17-site national school-based demonstration
program showed that a protocol involving weekly rinsing with 0.2% sodium fluoride was a practical alternative to professional applications. Caries reductions ranging from 20% to 50% were observed. These estimates of caries reduction have been criticized because these programs relied on a before-and-after design, with no concurrent comparison group during a period of time when caries was declining in the United States. Analyses of the NPDDP data showed that dental health lessons, brushing and flossing, fluoride tablets and mouth rinsing, and professionally applied topical fluorides were not effective in reducing a substantial amount of dental decay, even when all of these procedures were used together [16]. Another study on the island of Guam, using a combination of sealant and fluoride mouth rinsing, showed a 25.4% caries reduction, mainly on the proximal surfaces with fluoride mouth rinsing [39]. Caries declined from 7.06 DMFS at the baseline to 2.93 DMFS after 10 years among 6- to 14-year-old children [39].

**Cost-effectiveness**

According to Garcia [40], the cost of the procedure in 1988 ranged between $0.52 and $1.78 per child per school year, depending on whether paid or volunteer adult supervisors were used. At present, the cost of the product to rinse weekly in a school for 36 weeks is approximately $2.64 per child. The NPDDP conducted during the late 1970s, when downward trends of caries rates were noted, questioned the cost-effectiveness of rinse programs [16]. Many experts have concluded that fluoride mouth rinses may be more cost-effective when targeted at schoolchildren with high caries activity [2,37]. Since then, many states, like New York, have targeted the fluoride rinse program to high-risk schools in nonfluoridated areas.

**Fluoride tablet program**

In tablet form, dietary fluoride supplements can be chewed and swallowed to provide topical and systemic fluoride for children in the absence of optimally fluoridated drinking water. A National Health Interview Survey found that some 16% of children younger than 2 years of age reportedly used dietary supplements [41]. Similar to school-based mouth rinse programs, fluoride tablet programs are structured as a group activity in settings such as Head Start centers. There are also programs designed to provide fluoride tablets to children of migrant farm workers. Generally, these programs target high-risk children in nonfluoridated areas.

The fluoride supplement dosage schedule developed by the American Dental Association [42] is based on the level of fluoride in the community water supply and on the age of the child (Table 2). Fluoride supplements, however, should not be prescribed for individuals in communities where fluoride has been adjusted to optimal levels in the water or in places where optimal amounts of fluoride occur naturally in drinking water.
Effectiveness

Fluoride tablet programs in schools have been shown to be effective in preventing caries in permanent teeth when children are instructed to let the tablet dissolve slowly, to ensure as much topical fluoride exposure as possible. Under these conditions, randomized controlled trials in the United States reported caries reductions of 20% to 28% over periods of 3 to 6 years [43,44]. In a randomized, double-blind, 3-year study of Scottish schoolchildren who were 5.5 years of age at the start of the study, an 81% reduction in caries in permanent teeth was observed [45,46]. In this study, teachers were specifically requested to encourage children each school day to let the sodium fluoride tablet dissolve slowly. These children were likely at high risk for dental caries, because they were from lower socio-economic groups and may not have had access to fluoride-containing dentifrices. According to the Centers for Disease Control [12], while the evidence for school-based fluoride supplement programs for 6 to 16 year olds is strong, the quality of the evidence for programs in younger children is weak.

Cost-effectiveness

According to the Surgeon General’s report: Oral Health in America [2], school-based tablet programs have low costs because equipment is not necessary, the procedure does not take long, and an entire classroom of children can participate at once. In 1989, Garcia [40] found an average direct cost of approximately $2.53 per child per school year. While economic benefits of a fluoride supplement program in Manchester, England, showed overall health and cost benefits [46], an earlier study in the United States did not find fluoride supplements to be cost effective in a school-based program [14].

School-based fluoride tablet programs are likely to be effective in providing topical fluoride protection for children at high risk for dental caries in settings where supervising personnel are highly motivated [47,48]. Under these conditions, such programs may also be cost-effective [2].

### Table 2

Dietary fluoride supplement dosage schedule

<table>
<thead>
<tr>
<th>Age of child</th>
<th>Fluoride dosage (milligrams per day) at fluoride in water concentration of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 0.3 ppm</td>
</tr>
<tr>
<td>Birth to 6 months</td>
<td>None</td>
</tr>
<tr>
<td>6 months to 3 years</td>
<td>0.25</td>
</tr>
<tr>
<td>3–6 years</td>
<td>0.50</td>
</tr>
<tr>
<td>6–16 years</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Supervised tooth brushing programs with fluoridated toothpaste

In a supervised tooth brushing program, brushing is conducted once each day in the classroom or in Head Start centers using a fluoridated toothpaste. Teachers or other volunteers that are trained in an appropriate tooth brushing technique supervise the administration of the program. It requires trained personnel to ensure proper labeling and storage of toothbrushes. Two to four children are brought to a sink and a pea-sized amount of toothpaste is dispensed on the back of a paper cup by a Head Start staff or a classroom teacher. Children are instructed to brush for 1 minute and spit. In addition to the costs of the toothpaste and toothbrushes, the difficulty of storing toothbrushes and the labor-intensive nature of the program may be barriers for some sites.

Effectiveness

A systematic review of 70 controlled clinical trials of fluoridated toothpastes found that a greater amount of dental caries was prevented when tooth brushing was supervised [49]. This observation underscores the concept that the benefits of fluoridated toothpaste can be enhanced by structuring the environment to assure that children are brushing their teeth on a regular basis, and that this habit is instilled for a lifelong healthy behavior. A 2-year clinical trial of supervised tooth brushing in 5 year olds found a 32% reduction in caries increment attributable to the intervention in Scotland [50]. Similarly, an evaluation of a supervised tooth brushing program for 5 and 6 year olds in England found an 11% reduction in caries increment [51].

Cost-effectiveness

Data are not available on cost-effectiveness associated with supervised tooth brushing programs.

Fluoride varnish programs

Fluoride varnishes have been available as anticaries agents in Europe and Canada for over two decades. In the United States, it has been approved for use as a desensitizing agent. The varnishes are painted onto teeth and provide a reservoir of fluoride that is released over time in close proximity to the enamel surface. While fluoride retention from varnishes is greater than with solutions or gels, the varnishes must be reapplied by a professional to maintain their cariostatic effect. Recently, the American Dental Association Council on Scientific Affairs [52] summarized evidence and concluded that fluoride varnish applied every 6 months is effective in preventing caries in primary and permanent teeth of children and adolescents at risk for caries.
Fluoride varnish is attractive in a public health program because it can be easily incorporated into well-child visits to control early childhood caries. Innovative programs involving the application of fluoride varnish by physicians, nurses, and other health professionals to children have been initiated in many states. The North Carolina oral screening and fluoride varnish project, called “Into the Mouths of Babes,” is a collaborative effort among several partners [53]. The objective of the program is to train medical providers to deliver preventive oral health services to high-risk children from the time of tooth eruption until the third birthday. The preventive procedure consists of oral screening, individualized face-to-face parent or caregiver education, and application of fluoride varnish. Other states, such as Minnesota, Virginia, and Michigan have also developed programs to target Head Start children.

Effectiveness

Research on the effectiveness and costs associated with community-based fluoride varnish programs for high risk groups is ongoing. In the United States, a clinical trial conducted in young children showed that fluoride varnish was effective in reducing caries [54]. A meta-analysis conducted by Marinho and colleagues [55] showed that fluoride varnish could reduce caries in primary dentition by approximately one third.

Cost-effectiveness

The cost of application of fluoride varnish has been estimated to be in the range of $16 to $19 per application. A simulated analysis showed that fluoride varnish in the medical setting is effective in reducing early childhood caries in low-income populations, but is not cost saving in the first 42 months of life [56]. This can be attributed to the relatively low incidence of caries in this age group. The early intervention may yield cost savings in later years as children grow older and their risk for developing caries increases.

Salt fluoridation

Salt fluoridation is the controlled addition of fluoride to domestic salt for purposes of preventing dental caries. Similar to water fluoridation, a small amount of fluoride is widely distributed to the population in salt that is consumed on a daily basis. Like water fluoridation, salt fluoridation requires little effort on the consumer’s part.

Salt fluoridation is attractive where water supplies are low in fluoride. Switzerland, Colombia, Hungary, Costa Rica, Jamaica, and Mexico have all had considerable experience with salt fluoridation. It is estimated that 150 million individuals world-wide use fluoridated domestic salt (80 million in Europe, 70 million in Latin America and the Caribbean) [57].
Effectiveness

Community trials in Colombia and Hungary were conducted beginning in the 1960s to determine the effectiveness of salt fluoridation in preventing dental caries. These studies showed the reduction in dental caries prevalence to be about 50% in communities that had salt fluoridation programs [58]. These findings provide evidence that salt fluoridation reduced caries levels to an extent similar to water fluoridation.

Cost-effectiveness and cost savings

The cost of salt fluoridation has been estimated that for every dollar spent on salt fluoridation, about $250 in dental treatment costs are saved, making salt fluoridation an attractive public health investment [58].

Policy considerations

Public health policies should be based on sound science about risks, benefits, and economic evaluation of interventions to address a specific problem in a community. Decision makers should also consider the impact of not implementing a proven intervention. According to Brownson and colleagues [59], the control of chronic diseases is most effective if environmental and policy approaches are the earliest focus of change. Because individual behaviors are difficult to change in those who are especially at high risk, public health practitioners promote changes in the environment that benefit everyone. Some recent examples include the addition of folic acid to food grains to prevent neural tube defects, laws to prohibit smoking in public places, and restriction on the use of oils containing trans fats for cooking.

In the United States, water fluoridation is considered the cornerstone of a sound public health practice. Water fluoridation creates an environment conducive to promoting good oral health. Fluoridation delivers a sustainable level of fluoride to the oral environment on a frequent basis in an inexpensive way. It is a low-cost intervention that can reach large populations without active participation of the individuals. It provides preventive benefit across the spectrum of low and high socio-economic groups and may reduce disparities in oral health. Therefore, Healthy People 2010, a set of national objectives, has set a national goal of reaching 75% of the population on public water supplies. To reach this goal, the number of people on fluoridation should increase from 170 million to approximately 185 million.

The science based on effectiveness, safety, and the benefits of water fluoridation is extensive. It has been practiced in many countries for well over 50 years. In communicating the risks associated with water fluoridation, it is important to inform the community that benefits outweigh the risks. The only risk associated with the ingestion of fluoridated water at optimal levels is the occurrence of milder forms of enamel fluorosis [17]. In the United States, the decline in dental caries has also been accompanied...
by an increase in the prevalence of enamel fluorosis, both in fluoridated and nonfluoridated communities [60]. Undoubtedly, sources such as fluoride toothpaste ingestion during the development of teeth, and inappropriate use of fluoride supplements, have contributed to the excessive intake. Therefore, several steps have been taken to reduce fluoride exposure from various sources. These include a reduction in the fluoride content in infant formulas, revision of the fluoride supplement schedule, and recommendations to lower fluoride exposure from toothpastes for children under age 6 [12].

Discussions about fluoridation of a particular community should focus on the disease burden, feasibility, cost, and use of other forms of fluoride. Decision makers should be made aware of the benefits and risks. While exposure to fluoridation and daily use of fluoride toothpaste is sufficient for most Americans, some individuals may need additional targeted interventions. In areas where fluoridation is not available, an alternative public health program may be considered.

Summary

The use of fluorides in dental public health programs has a long history. With the availability of fluoridation and other forms of fluorides, dental caries has declined dramatically in the United States. Fluoride acts both topically after the eruption of teeth and systemically through its incorporation into enamel crystals. The science based on effectiveness, safety, and the benefits of water fluoridation and other forms of fluoride is extensive. For most people, fluoride exposure through water fluoridation and regular tooth brushing is sufficient. Routine application of topical gels or foams for 1 minute is no longer supported by evidence. Populations at high risk may need additional exposure through other forms of fluorides. In areas where fluoridation is not available, an alternative public health program may be considered.

References


