Is Water Fluoridation Still Necessary?

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Water fluoridation has been promoted in many countries as an organized community effort to control dental caries. With the availability of fluorides targeted at individuals and the decline in dental caries, the need for fluoridation has been questioned. Recent reports show that water fluoridation, a community-level intervention, continues to be an efficient method for the delivery of fluoride in many countries. The advantages include its ability to deliver low levels of fluoride to saliva frequently, with high reach, at low cost, and with substantial cost savings. Water fluoridation has the potential to reduce oral health disparities by creating a healthy environment. Other forms of fluoride, such as fluoride toothpaste, and clinical interventions complement dental caries control strategies.

Introduction

Fluoridation has been promoted in many countries as an organized community effort to meet the health, economic, and societal challenges of dental caries (Clarkson and McLoughlin, 2000; Petersen and Lennon, 2004; Jones *et al.*, 2005). It is adopted because the underlying problem is widespread, the disease burden is distributed unfairly, the evidence of preventive intervention is strong, and alternative strategies are not reaching those who need them the most. This approach complements other self-applied fluoride strategies and clinical interventions designed to control dental caries. Other approaches, such as health education efforts to bring about changes in individual behavior and dietary control, have not shown impressive results (Kay and Locker, 1996).

Foods and beverages have been used as vehicles for delivering nutrients and minerals for many decades. The addition of folic acid to cereals and grains for eliminating neural tube defects is a prime example. Policies pursued by different countries to use these vehicles for addressing public health problems vary, depending on the disease burden, health priorities, political philosophy, economic situation, health care system, and feasibility. While fortification of cereals and grains with folic acid has been mandated in the United States since 1996, many European countries have been slow to adopt this (Oakley, 2002). Similarly, policies regarding the selection of fluoride as a preventive modality vary widely across different countries. For example, Vietnam has recently undertaken efforts to promote fluoridation, whereas it has been discontinued in the former East Germany. While Switzerland and some South American countries have promoted salt fluoridation, Scandinavian countries have relied on school-based programs (Jones *et al.*, 2005; Marthaler and Petersen, 2005).

The question posed in this symposium is fair, because all public health interventions should be periodically re-examined. Caries in children has declined in the absence of fluoridation in some countries. Our thinking about fluoride's mechanisms of action has changed. The effect of fluoride is considered primarily, though not exclusively, post-eruptive (CDC, 2001). A narrowing in the difference in caries rates between fluoridated and non-fluoridated communities has been observed. Many other forms of fluorides are now available, especially fluoride toothpastes in developed countries. To answer the question posed in this symposium, I undertook a review to examine the issues mentioned above, with particular relevance to fluoridation policy in the United States. Healthy People 2010, a set of national health objectives, calls for at least 75% of the population served by community water systems to receive optimal levels of fluoride (US Department of Health and Human Services, 2000b).

Although dental caries experience has declined in the United States, it still affects a large proportion of the population (Beltran-Aguilar *et al.*, 2005), and it is the most common chronic childhood disease. Almost 20% of 2- to 5-year-old children experience caries. Among 16- to 19-year-old children, the average number of decayed, missing, and filled surfaces is 5.8. Adults 40 to 59 years of age have an average 42 decayed, missing, and filled surfaces (DMFS). Only about 50% of children visit a dentist annually. The societal cost is enormous, since dental diseases account for 30% of all health care expenditures in children (US Department of Health and Human Services, 2000a). In general, the disease burden is higher among the poor and minorities. This assumes greater importance when one considers that one in four children in the United States lives in poverty.

Effectiveness of fluoridation

Several recent and authoritative reviews conducted in the US, Australia, the UK, and Ireland provide evidence of the effectiveness of water fluoridation under modern conditions (McDonagh *et al.*, 2000; Government of Ireland, 2002; Truman *et al.*, 2002; National Health and Medical Research Council, 2007). Two systematic reviews are examined here to quantify the effect of water fluoridation (Table 1). The National Health Centre for Reviews and Dissemination, University of York, concluded that the best available evidence suggested that fluoridation of drinking water supplies reduced dental caries prevalence, as measured both by the proportion of children who are caries-free and by the mean reduction in the decayed, missing, and filled teeth (dmft/DMFT) score (McDonagh *et al.*, 2000).

An independent Task Force convened by the Centers for Disease Control and Prevention (CDC), which developed the *Guide to Community Preventive Services*, found strong evidence that water fluoridation is effective in reducing the cumulative caries experience (Truman *et al.*, 2002). 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

Key Words

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TABLE 1. Effectiveness of Fluoridation as Estimated in Two Systematic Reviews

Review	Reviewed Studies' Characteristic	Interest Outcomes	Outcome Changes: Median (range)
National Health Centre for Reviews and Dissemination[a]	Before/after community water fluoridation (CWF)	Changes in caries prevalence	-15%* (-64%, 5%)
		Differences in dmft/DMFT	-2.25 (-0.5, -4.4)
The Community Guide[b]	Before/after	Changes in caries at the tooth level (deft/DMFT)	
		Effect of starting or continuing CWF	-29.1% (-110.5%, 66.8%)
		Effect of stopping CWF	17.9% (-42.2%, 31.7%)
	After measure only	Changes in caries at the tooth level (deft/DMFT)	
		Effect of starting or continuing CWF	-50.7% (-68.8%, -22.3%)
		Effect of stopping CWF	59.9%

* Negative values reflect decrease in caries.
a McDonagh *et al.* (2000).
b Truman *et al.* (2002).

aged 4 to 17 years by a median of 29.1% during 3 to 12 years of follow-up. Stopping fluoridation was associated with a median increase of 17.9% increase in dental caries during 6 to 10 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.

Several recent reports in the United States show that the difference in dental caries between fluoridated and non-fluoridated communities is still noticeable, despite the ubiquitous presence of fluoride in food, water, and dental products (Jackson *et al.*, 1995; Selwitz *et al.*, 1995, 1998; Kumar *et al.*, 2001). Additional supportive evidence comes from studies conducted in Australia and Ireland (Slade *et al.*, 1995, 1996; Government of Ireland, 2002; Armfield, 2005; Hopcraft and Morgan, 2006).

Although the benefit of water fluoridation is measured in terms of caries averted, there are many intangible benefits. There is a general impression that the progression of caries is delayed in the presence of fluoride, thereby providing more time for undertaking restorative treatment, when compared with 50 years ago (Lawrence and Sheiham, 1997). The disease in children is also now less complex to treat, since most of the lesions are in pits and fissures (Brown and Selwitz, 1995). The benefits continue into adulthood (Griffin *et al.*, 2007).

Diffusion effect

Another advantage of fluoridation is that even persons in non-fluoridated areas also receive fluoride through beverages and foods originally processed in fluoridated areas (Pang *et al.*, 1992). This diffusion of fluoride through beverages and foods is thought to provide an explanation for the diminished difference in caries observed in recent years between fluoridated and non-fluoridated communities (Ripa, 1993; Griffin *et al.*, 2001a). 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 that in children with no exposure to fluoridation (Brunelle and Carlos, 1990). The mean DMFS difference in the 5- to 17-year-old children amounted to almost 61% in the Western region of the United States, where the fluoridation penetration was only 19%. In regions where the fluoridation reached greater than 50%, the difference was much smaller or difficult to observe. The diffusion effect has been quantified by measurement of the differences in mean DMFS between and among communities with different diffusion exposures (Griffin *et al.*, 2001a). This analysis showed that a direct comparison of mean DMFS between fluoridated and non-fluoridated communities underestimated the effectiveness of water fluoridation. This has important implications for the discontinuation of water fluoridation, since caries levels would rise not only in fluoridated communities, but also in non-fluoridated communities if the fluoride exposure levels were not maintained.

Cost and savings

The more relevant issue now is to examine if water fluoridation results in cost savings. An analysis of cost savings is primarily based on the cost of water fluoridation and the costs of disease averted, including productivity losses averted. Many factors—such as equipment, construction, chemicals, and labor—affect the cost of fluoridating a community (Griffin *et al.*, 2001b). The size of the community and the number of injection points are the major determinants. 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 ≤ 5000 to $0.40 for systems serving ≥ 20,000 people (Truman *et al.*, 2002).

The National Preventive Dentistry Demonstration Program concluded that water fluoridation was the most cost-effective means of reducing tooth decay in children. The reductions in decay attributable to water fluoridation were almost the same as those obtained with sealants, but at a much lower cost (Klein *et al.*, 1985). The annual *per* person cost savings, in 1995 dollars, from water fluoridation has been estimated for communities of different sizes by various parameters, such as effectiveness, annual caries increment, average discounted lifetime cost of a carious surface, and cost of fluoridation (Griffin *et al.*, 2001b) (Table 2). This analysis assumed that there are no adverse effects from fluoridation. The number of carious surfaces saved that is attributable to foregoing one year of water fluoridation is estimated to be 0.04, 0.19, and 0.34, for worst-, baseline, and best-case scenarios (in terms of effectiveness), respectively. Using similar methods, O'Connell *et al.* (2005) estimated that

TABLE 2. Annual *per* Person Cost Savings (in 1995 dollars) (negative net cost) from Water Fluoridation in the United States

Community Size (population)	Best Case*	Baseline	Worst Case
< 5000	$31.04	$15.95	$0.85
5000-9999	$32.57	$17.48	$2.38
10,000-20,000	$33.15	$18.06	$2.96
>= 20,000	$33.71	$18.62	$3.52

* The numbers of carious surfaces attributable to foregoing one year of water fluoridation exposure are 0.34, 0.19, and 0.04 surfaces for best-, baseline, and worst-case scenarios, respectively. The estimated annual *per* person water fluoridation costs for communities of various sizes varied from a low of $0.50 to a high of $3.44. For a community with a population > 20,000, the return on investment was calculated based on the baseline scenario: total savings ($18.62 + $0.50)/cost of fluoridation provided by the author ($0.50) = $38 (1995 US dollars) (Griffin *et al.*, 2001b).

the fluoridation program in Colorado was associated with an annual saving of $148.9 million (credible range, $115.1 to 187.2 million) in 2003, or an average of approximately $61 *per* person (O'Connell *et al.*, 2005). Similar results have also been observed in New Zealand (Wright *et al.*, 2001). The impact of fluoridation on the cost of publicly financed treatment programs has also been reported from Texas and Louisiana (CDC, 1999; Texas Department of Health, 2000).

Mechanism

The improved understanding of the mechanisms of fluoride action has led to the conclusion that the predominant action of the fluoride is in the processes of remineralization and inhibition of demineralization of enamel (Featherstone, 1999, 2000). While this mechanism was not well-understood when fluoridation was introduced, the post-eruptive benefits were recognized even in the early epidemiological studies of fluoridation (Ast *et al.*, 1956). For example, the percent of caries-free first permanent molars that had already erupted in 16-year-olds when fluoridation was initiated in Newburgh was 8.5, compared with 4.8 in non-fluoridated Kingston. There were also fewer missing first permanent molars in Newburgh. These initial studies suggested that there were beneficial effects on teeth that were formed or erupted prior to the initiation of water fluoridation (McClure, 1970). While the post-eruptive benefits are acknowledged, it is the pre-eruptive benefits that are debated, especially in the context of fluoride supplement use.

The relative beneficial effects of pre- and post-eruptive exposure have been studied in Australian children (Singh *et al.*, 2003; Singh and Spencer, 2004). The results suggested an important pre-eruptive caries-preventive effect and supported continuous exposure for the best outcome. The authors noted that a thin fluorapatite coating on the surfaces of hydroxyapatite crystals could lead to decreased solubility of enamel. This finding supports that of an earlier study, conducted in India, which examined trends in dental caries attack rates in permanent first molars after the source of fluoride was changed from higher (0.9 to 2.0 mg/L) to lower (0.19 mg/L) in three villages (Kaur *et al.*, 1987). Remarkably, older children, who had relatively more pre-eruptive exposure and little post-eruptive exposure, had better outcomes. Because studies to separate the pre-eruptive effects from the post-eruptive effects are difficult to design and conduct, this debate will probably continue without further epidemiological studies. Regardless of the predominant mechanism of action, water is an efficient vehicle for delivering a low concentration of fluoride at high frequency.

Disparities in health and social equity

In the early part of the last century, dental caries was considered a disease of the rich, due in part to their greater access to refined sugar. An analysis of the WHO database suggested that a pattern of change in caries prevalence has emerged (Peterson, 2003), showing that caries has declined in many industrialized countries, but has increased in some developing countries. With the introduction of fluoride, improved oral hygiene practices, and early restorative care, dental caries trends show a substantial decline in many industrialized countries. Because not all segments of the society benefited equally from the improvement in oral health, dental caries has now become a disease of the poor in most Western countries. Reducing or eliminating oral health disparities is a goal for many countries.

The National Health Centre for Reviews and Dissemination at the University of York examined whether fluoridation reduced dental caries across social groups in Britain (McDonagh *et al.*, 2000). Using the dmft/DMFT measure, the authors noted that there appeared to be some evidence that water fluoridation reduced the inequalities in dental health across social classes in 5- and 12-year-olds, but not the proportion of caries-free children among 5-year-olds. Several other investigators in Australia, New Zealand, and the United States have reported that disadvantaged children have the worst outcome in the absence of water fluoridation (Slade *et al.*, 1996; Kumar *et al.*, 1998; Wright *et al.*, 2001). More recently, a study found that, while everyone living in fluoridated areas in New South Wales had lower caries experience, indigenous people, who represent one of the most marginalized and disadvantaged segments of the Australian population, benefited more from water fluoridation (Armfield, 2005).

Enamel fluorosis and water fluoridation

The only known risk associated with the ingestion of fluoridated water is the occurrence of milder forms of enamel fluorosis (McDonagh *et al.*, 2000). In the United States, the decline in dental caries has also been accompanied by an increase in the prevalence of enamel fluorosis, in both fluoridated and non-fluoridated communities (Rozier, 1999). Several steps have been taken to reduce fluoride exposure from various sources. These include: a reduction in the fluoride content in infant formulas; the introduction of low-concentration fluoride toothpastes for children in Australia and Europe; downward adjustment of fluoride in water in Hong Kong, Canada, and Ireland; and downward adjustments in fluoride supplement regimens. Studies in Hong Kong and Australia have observed a reduction in the prevalence of dental fluorosis pursuant to specific changes in fluoride exposure (Evans and Stamm, 1991; Riordan, 2000). In the United States, a clear population threshold exists for severe enamel fluorosis, such that the occurrence of the advanced form of fluorosis is close to zero in areas where the fluoride level in drinking water is below 2 mg/L (National Research Council, 2006).

Discussion

Water fluoridation is a population-level strategy for preventing dental caries. As such, it has broad reach in the population, with demonstrated safety, effectiveness, and low cost. Fluoridation delivers sustainable level of fluoride to the oral environment on a frequent basis in an inexpensive way. The return on investment is attractive in most communities, even under the assumptions of worst-case scenario regarding its effectiveness and cost.

Water fluoridation is still necessary for promoting good oral health, since changes in individual behaviors are difficult to accomplish, especially among certain segments of society (Burt, 2002). The alternative strategies, such as supervised toothbrushing in schools, are difficult to implement and sustain. While randomized clinical trials show strong evidence for promoting toothpaste use, these findings are difficult to generalize to diverse community settings. A recent systematic review of toothpaste clinical trials showed that the annual mean increment in the control group where it was tested ranged from 1.14 DMFS to 7.66 DMFS (Marinho *et al.*, 2003). In contrast, economic analyses have been conducted based on annual caries increments of 0.33 to 1.16 DMFS observed in the United States (Griffin *et al.*, 2001b). The return on investment is significant, even when the caries-preventive effectiveness is modest. Analyses of the National Preventive Dentistry Demonstration Program data showed that dental health lessons, brushing and flossing, fluoride tablets and mouthrinsing, and professionally applied topical fluorides were not effective in reducing a substantial amount of dental decay, even though many of these interventions have been shown to be effective in clinical trials. Water fluoridation was shown to prevent as much decay as the placement of dental sealants (Klein *et al.*, 1985).

The studies of the effectiveness of water fluoridation have been based on observational study designs. As such, these studies are considered lower in quality. However, the weight of evidence derived from the observational studies conducted in diverse population groups provides convincing evidence of the effectiveness of water fluoridation.

Discussions about fluoridation of a particular community should be viewed in the context of available caries-prevention strategies and focused on the disease burden, feasibility, cost, and utilization of other forms of fluoride. Similarly, discussions concerning cessation of fluoridation should consider the impact of removing the intervention from socially disadvantaged groups within the community.

The title of this paper asks whether water fluoridation is still necessary. At present, fluoridation remains the best tool to combat caries in many countries. Another way to consider the question is to ask, What evidence is there to show fluoridation to be unnecessary in the countries where it is widely practiced? An alternative strategy for preventing dental caries across all social strata in the population has not emerged, while the costs of treatment have not declined.

Measuring the impact of interventions to control dental caries is difficult, because it is characterized by a complex interaction of multiple risk factors. Documenting the impact of fluoridation is even more challenging, because the immediate impact is not apparent. Therefore, research should continue to asses its impact and to determine the appropriate level of fluoride in water to balance the benefits of fluoride against the risks of enamel fluorosis in any one country. Similarly, surveillance and research activities should continue to assess the effect of total fluoride exposure. Promising new approaches to eliminate dental caries as a public health problem should be pursued.

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