Economic Evaluation of Community Water Fluoridation

A Community Guide Systematic Review

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Context: A recently updated Community Guide systematic review of the effectiveness of community water fluoridation once again found evidence that it reduces dental caries. Although community water fluoridation was found to save money in a 2002 Community Guide systematic review, the conclusion was based on studies conducted before 1995. Given the update to the effectiveness review, re-examination of the benefit and cost of community water fluoridation is necessary.

Evidence acquisition: Using methods developed for Community Guide economic reviews, 564 studies were identified within a search period from January 1995 to November 2013. Ten studies were included in the current review, with four covering community fluoridation benefits only and another six providing both cost and benefit information. Additionally, two of the six studies analyzed the cost effectiveness of community water fluoridation. All currencies were converted to 2013 dollars.

Evidence synthesis: The analysis was conducted in 2014. The benefit-only studies used regression analysis, showing that different measures of dental costs were always lower in communities with water fluoridation. For the six cost-benefit studies, per capita annual intervention cost ranged from $0.11 to $4.92 for communities with at least 1,000 population, and per capita annual benefit ranged from $5.49 to $93.19. Benefit–cost ratios ranged from 1.12:1 to 135:1, and these ratios were positively associated with community population size.

Conclusions: Recent evidence continues to indicate that the economic benefit of community water fluoridation exceeds the intervention cost. Further, the benefit–cost ratio increases with the community population size.

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Context

Dental caries is a microbiological disease of the hard structure of teeth, exposed in the oral cavity, that results in localized demineralization of the inorganic portion and destruction of the organic substances of the tooth, beginning on the external surface.[1] It can lead to loss of tooth structure and discomfort, or severe pain and bacterial infection. If severe, dental caries can lead to very young children receiving dental care in a hospital operating room under general anesthesia, school-aged children experiencing loss of school time and lower grades, and adults having poorer productivity and quality of life. As a result, dental caries can impose a significant economic burden both to the individual and to society as a whole. In 2013, expenditures on dental services in the U.S. reached $111 billion.[2]

Fluoride is effective in decreasing the incidence of dental caries. It acts in various ways to prevent tooth decay by inhibiting bacterial metabolism and demineralization, and enhancing remineralization by affecting the surface of the tooth, especially when low concentrations of fluoride are consistently maintained in the mouth.[3] Community water fluoridation (CWF) is the controlled adjustment of fluoride in a public water supply to optimal concentration in order to prevent

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caries (tooth decay) among members of the community (www.thecommunityguide.org/oral/fluoridation.html). CWF is regarded as the single most effective public health measure to prevent tooth decay in the U.S.[4] and was among the top ten greatest public health achievements of the 20th century.[5] From the individual perspective, water fluoridation prevents tooth decay by providing frequent and consistent contact with low levels of fluoride. By keeping the tooth strong and solid, fluoride stops cavities from forming and can even rebuild the tooth's surface.[6] Therefore, CWF helps to improve oral health and enhance quality of life. Moreover, CWF requires changes only in environment and policy instead of in individual behavior. In addition, it is population-based, covering large segments of a population at a low cost.[7] In fact, a Chilean analysis[8] found CWF to be the second most cost-effective oral health intervention next to salt fluoridation (which is not currently used in the U.S.).

Following an updated systematic review on the effectiveness of CWF in April 2013, the Community Preventive Services Task Force (Task Force) recommended CWF based on strong evidence of effectiveness in reducing dental caries across populations (www.thecommunityguide.org/oral/fluoridation.html). Evidence showed that the prevalence of caries was substantially lower in communities with CWF. In addition, there was no evidence that CWF resulted in severe dental fluorosis (an enamel defect ranging in severity from barely noticeable white spots in mild forms to staining and pitting in more severe forms[9]).

A 2002[10] comprehensive review of oral health interventions indicated that CWF saved money from a societal perspective. The nine included studies in the review were conducted from the early 1970s to the end of 1994. Given the updated systematic review on the effectiveness of CWF and the change in the economic environment, an up-to-date systematic review on the cost and benefit of CWF is necessary. This review focuses on the economic studies of CWF conducted after January 1995. The research questions are as follows:

1. What is the cost of CWF based on information after January 1995?
2. What are the relevant cost-effectiveness or cost–benefit estimates for CWF?

Evidence Acquisition

General methods for Community Guide systematic economic reviews are available at www.thecommunityguide.org/about/economics.html. This review was conducted under the oversight of the Task Force, by federal and non-federal scientists, and specialists in systematic review methods and in research and policy related to oral health.

Multiple databases were used for the systematic search: PubMed, EconLit, ERIC, JSTOR, Social Sciences Citation Index, databases at the Centre for Reviews & Dissemination at the University of York, and the Health Economic Evaluations Database from Wiley. To identify relevant studies, economic search terms (shown in Appendix 1, Section C, available online) were used in the search strategy, in addition to effectiveness and subject keywords. Further, a secondary manual search was conducted using Google Scholar. Finally, a subject matter expert from the Division of Oral Health, CDC, was consulted for additional studies.

The inclusion criteria followed the standard for economic evaluation studies adopted by the Community Guide.[11] Studies were included if they evaluated a community water fluoridation intervention and

1. provided information on cost or benefit of CWF;
2. were primary studies, in the form of a peer-reviewed paper or report;
3. were conducted in high-income countries as defined by the World Bank (data.worldbank.org/about/country-and-lending-groups); and
4. were written in English and published between January 1995 and November 2013.

Once the preliminary list of papers was identified, title, abstract, and full text screening were conducted to finalize the selected studies. The final studies used one or more of the following economic measures: intervention cost, change in treatment cost or dental visits/claims, benefit–cost ratio, and dollars per disability-adjusted life year (DALY) averted. For studies having cost and benefit information but not benefit–cost ratios, the ratio was calculated by the reviewers. The analysis was conducted in 2014.

To ensure comparability among the studies, costs and expenditures were adjusted to 2013 U.S. dollars using the consumer price index (CPI) from the Bureau of Labor Statistics (data.bls.gov/pdq/querytool.jsp?survey=cu). A general CPI was used instead of the CPI for medical services, because not every cost/benefit variable extracted from the studies was from the medical sector. Thus, the general CPI provides a conservative estimation for inflation adjustment. International currencies were converted to U.S. dollars using purchasing power parity rates from the World Bank (data.worldbank.org/indicator/PA.NUS.PPP). Purchasing power parity rates were used because "they are less susceptible to financial flows and governmental exchange rate manipulation than are market exchange rates."[11]

Once the intervention cost and benefit were comparable among the studies, major contributors to the variation in cost and benefit were identified. Finally, economic evidence was summarized. Limitations of the studies as well as evidence gaps were also listed.

Evidence Synthesis

Search Results

A total of 564 papers were identified in the initial literature search, of which 508 were excluded after the first screening of titles and abstracts because they did not meet the inclusion criteria. Another 48 papers were excluded after the second screening of the full text. This yielded eight papers from the database search. With two additional papers recommended by the subject matter expert, the final search yield included ten studies (Figure 1). A summary evidence table with details of the ten studies is at www.thecommunityguide.org/oral/supportingmaterials/SET-waterfluoridation-econ.pdf.

Characteristics of Studies

The final ten studies were eight peer-reviewed journal articles[7,12–18] and two reports.[19,20] Geographically, six of the studies were from the U.S.,[7,14–16,19,20] with the rest from Australia,[12,13] Canada,[17] and New Zealand.[18] Six papers[12–14,16–18] provided cost and benefit information, two[12,13] of which also conducted cost-effectiveness analysis using DALYs. The remaining four papers[7,15,19,20] provided only benefit information and used regression models to analyze the change in treatment cost or dental claims with the presence of CWF.

Intervention Cost

Conceptually, the intervention cost of CWF is composed of a *one-time investment cost*, which is amortized to obtain annual value, a *recurrent fixed cost*, and a *variable recurrent cost. One-time investment cost* refers to investments in fluoridation facilities. *Recurrent fixed cost* includes cost of maintenance; operation (including staff cost); and monitoring. *Variable recurrent cost* refers to cost that varies with quantity of water fluoridated. Six of the ten studies included in the review provided cost information. All intervention cost was estimated. Table 1 provides the details of intervention cost for the six studies.[12–14,16–18]

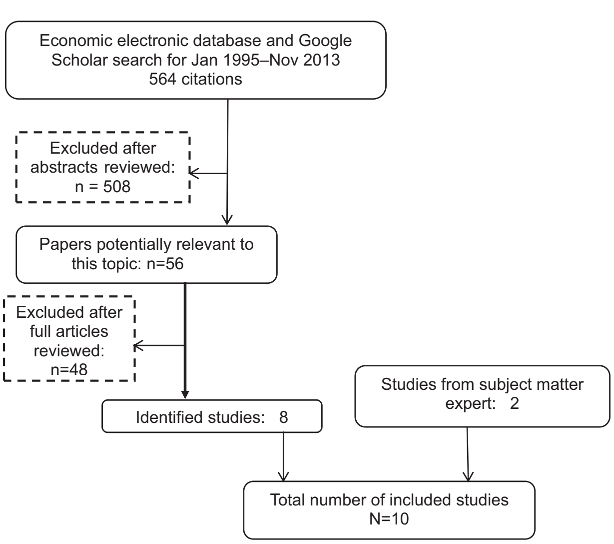

Figure 1. Flowchart showing economic evidence search yield.

Of the six studies, Tchouaket et al.[17] provided information on the salary and working hours of the technicians (including consulting fees for part-time dentists), based on which the major recurrent cost was calculated. They also mentioned the cost of using a public health laboratory, as well as that of purchasing supplies, as variable recurrent cost. Per capita annual cost was calculated by dividing the estimated annual total cost of the province of Quebec (including amortized one-time investment cost, recurrent fixed cost, and variable recurrent cost) by the total population of Quebec as $1.63 using a 3% discount rate for fixed cost. Wright and colleagues[18] consulted equipment providers and operators of fluoridation systems and provided detailed information on capital investment and cost for different community sizes. Their per capita annual cost ranged from $0.11 for a community population of 300,000 to $4.92 for a community population of 1,000. Both Griffin et al.[14] (whose per capita annual cost ranged from $0.76 for population size >20,000 to $4.85 for population size <5,000) and O'Connell and colleagues[16] (whose cost ranged from $0.54 for population size ≥20,000 to $3.36 for population size of 1,000) used the cost data in Ringelberg et al.,[21] with O'Connell and colleagues[16] adjusting chemical cost estimates in Ringelberg et al.[21] downward because several Colorado systems had moderately high levels of naturally occurring fluoride. Cobiac and Vos[13] ($0.24 for urban area) used the cost information in Campain and colleagues[22]; Ciketic et al.[12] ($0.81) used information from a "scoping report on fluoridation that was done for the Queensland Government in 2002." The estimated per capita annual costs were comparable among the studies, except for the $24.38 for <1,000 community in Cobiac and Vos.[13] Cobiac and Vos attributed the high cost to the rural nature of the small community, where people were more scattered compared with urban communities.

Per capita annual cost ranged from $0.11 to $4.92 in 2013 U.S. dollars for communities with ≥1,000 population. The variation in per capita annual cost was mainly attributable to community population size. Specifically, per capita annual cost decreased as population size increased, after adjusting for factors such as discount rate. The same pattern was shown in the original review,[10] where the median per capita annual cost for a community with ≤5,000 people was $2.70 (assumedly in 2001 U.S. dollars) and that for a community with ≥20,000 people was $0.40. This implies economies of scale on the cost side. Graphical illustrations of the pattern in the current review are presented in Appendix Figures 1 and 2 (available

Table 1. Per Capita Annual Cost of Community Water Fluoridation (3% Discount Rate)

Study, year	Location	Community population size	Time horizon (years)	Per capita annual cost (original currency)	Per capita annual cost (2013 dollars)
Ciketic (2010)[12]	SE Queensland, Australia	NR	15	0.84	0.81
Cobiac (2012)[13]	Australia	<1,000 ≥1,000	15 15	26.0 0.26	24.38 0.24
Griffin (2001)[14,a]	U.S.	<5,000 >20,000	15 15	3.17 0.50	4.85 0.76
O'Connell (2005)[16]	Colorado, U.S.	1,000 ≥20,000	15 15	2.66 0.43	3.36 0.54
Tchouaket (2013)[17]	Quebec, Canada	NR	20	1.86	1.63
Wright (2001)[18,b]	New Zealand	1,000 >300,000	30 30	5.20 0.12	4.92 0.11

[a]4% discount rate.
[b]Calculated by the reviewer by dividing total cost by 30 years and the population size, assuming 5% discount rate.
NR, not reported.

online). Both figures show that per capita annual cost was the highest when population size was around 1,000. As community population size increased, per capita annual cost decreased. In particular, per capita annual cost for communities with ≥20,000 population was <$1.

Intervention Benefit

Generally, intervention benefit was composed of averted healthcare cost, productivity loss, and other losses. Healthcare cost included expenditure on examination; restoration (including lifetime cost of maintaining the restoration such as repairing or replacing a filling); and extraction. Productivity loss was mainly related to loss of work time because of dental visits. Other losses included transportation cost to dental facilities. All ten studies provided benefit information. Four[7,15,19,20] of them covered benefit only; the remaining six[12–14,16–18] also provided estimates of intervention cost.

Regression analysis was used in the four benefit-only studies[7,15,19,20] (findings listed in Appendix Table 1, available online), whose benefit was mainly composed of treatment cost averted, either as dental treatment averted or claims avoided. Although differences existed in their dependent variables and magnitudes of the estimates, all studies reached similar conclusions: The presence of CWF was related to lower dental treatment cost and fewer claims.

Per capita annual benefit of the six studies[12–14,16–18] that provided both benefit and cost information ranged from $5.49 to $93.19, with details shown in Table 2. One of the main causes of variation in benefit was the number of benefit components included in the studies. Benefit components for the six studies[12–14,16–18] are presented in Appendix Table 2 (available online). For example, Tchouaket and colleagues[17] included the most benefit components among the studies (five components). Additionally, they used the Decayed-Missing-Filling Teeth index (DMFT, which measures the prevalence of dental caries) or Decayed-Missing-Filling index for deciduous teeth (dmft) as a proxy for caries increment in Quebec. Those facts might explain why their per capita annual benefit was the highest. By contrast, Wright et al.[18] had only two components, excluding lifetime treatment cost averted. Consequently, the benefit in Wright and colleagues was the lowest. In addition, per unit dental treatment cost and lost productivity cost varied with locations. This also contributed to the difference in healthcare cost averted among the studies. Information on per unit cost of dental treatment and of productivity is available in Appendix Table 3 (available online).

Of note, the majority of the studies assumed similar caries reduction rates in estimating the benefit. Specifically, 20% was assumed in O'Connell et al.[16] Cobiac and Vos[13] assumed 15% effectiveness based on the McDonagh and colleagues[23] systematic review. Griffin et al.[14] provided information on three scenarios: worst case (4%); base case (19%); and best case (34%). Their base case (19%) is reported in Table 2. Similarly, Tchouaket and colleagues[17] conducted sensitivity analysis with effectiveness ranging from 1% to 50%. Twenty percent was reported in this review. Wright et al.[18] had 33% effectiveness because of the 15% Maori population in New Zealand. Overall, the assumptions in the six studies were consistent with the result from the

Table 2. Community Water Fluoridation per Capita Annual Benefit (3% Discount Rate)

Study, year	Location	Number of components	Caries reduction rate (%)	Per capita annual benefits (original currency)	Per capita annual benefits (2013 dollars)
Ciketic (2010)[12]	Australia	1	NR	14.68	14.19
Cobiac (2012)[13]	Australia	2	15	NR	NR
Griffin (2001)[14,a]	U.S.	3	19	19.12	29.23
O'Connell (2005)[16]	Colorado, U.S.	4	20	58.05	73.50
Tchouaket (2013)[17]	Quebec, Canada	5	20	106.42	93.19
Wright (2001)[18,b]	New Zealand	2	33	5.80	5.49

[a]4% discount rate.
[b]Calculated by the reviewer by dividing total benefit by 30 years and the population size, assuming 5% discount rate.
NR, not reported.

effectiveness review (a median of 14.6% by McDonagh and colleagues,[23] and 25.1% by the Community Guide effectiveness review[9]).

Benefit–Cost Ratios

Table 3 lists the benefit–cost ratios of the six studies that provided cost and benefit information. Some benefit–cost ratios were presented in the papers (such as O'Connell et al.[16] and Tchouaket and colleagues[17]), whereas others were calculated based on information available in the studies (Wright et al.,[18] Griffin and colleagues,[14] Cobiac and Vos,[13] and Ciketic et al.[12]). The benefit–cost ratios varied with community size. Additionally, other factors (such as the number of benefit components) that contributed to the variations in benefit also accounted for some of the variation in benefit–cost ratios.

Despite other causes of variation, benefit–cost ratios generally increased with community population sizes, mainly due to the economies of scale on the cost side. Graphical illustrations of the association are presented in Appendix Figures 3 and 4 (available online). The most frequently cited benefit–cost ratio (38:1) in the U.S. was calculated using a 4% discount rate and 19% caries reduction from Griffin and colleagues[14] for communities with populations $>$20,000.

In summary, benefit–cost ratios were larger than 1.0 for communities of at least 1,000 people, indicating that CWF was cost beneficial for communities with no fewer than 1,000 people.

Cost-Effectiveness Analysis Results

DALYs averted was used in two studies[12,13] on cost-effectiveness analysis (Appendix Table 4, available online). For both studies, the cost/DALYs averted was well below the per capita annual income of Australia (approximately $30,000 in 2013 U.S. dollars), which was

Table 3. Benefit–Cost Ratio (3% Discount Rate)

Study, year	Location	Community size	Number of components	Benefit–cost ratio
Ciketic (2010)[12]	SE Queensland, Australia	NR	1	17.51:1
Cobiac (2012)[13]	Australia	$\geq$1,000	2	37.69:1[a]
Griffin (2001)[14,b]	U.S.	$<$5,000 $>$20,000	3 3	6.03:1 38.24:1
O'Connell (2005)[16]	Colorado, U.S.	1,000 $\geq$20,000	4 4	21.82:1 135:1
Tchouaket (2013)[17]	Quebec, Canada	NR	5	57.21:1
Wright (2001)[18,c]	New Zealand	1,000 $>$300,000	2 2	1.12:1 48.79:1

[a]Calculated by dividing the total benefit by total cost.
[b]4% discount rate.
[c]5% discount rate.
NR, not reported.

used as a threshold for cost comparison with DALYs averted.

Discussion

The benefit of CWF exceeding cost suggests a positive rate of return for investment in CWF interventions. This is consistent with the findings from the previous Community Guide review,[10] which indicated that CWF saved money from a societal perspective and also reduced caries.

Owing to the nature of the intervention, it would be very costly to obtain the actual benefit information of CWF. Therefore, the benefits of CWF in all the included economic studies were estimated, based on comparable assumptions of effectiveness rates. Furthermore, estimated intervention cost was used as a proxy for societal cost. This might cause the cost to be underestimated. Ko and Thiessen[24] illustrated a more comprehensive way to estimate societal cost, although their examples might not be typical. Even though the variation in estimated cost among the studies included in this review was small (after adjusting for discount rate and population size), future studies should focus on actual cost data if they are available. Furthermore, other costs such as political cost (e.g., expenses associated with promoting CWF), or cost of fluorosis, if there is clear evidence of severe dental fluorosis, should be included.

Additionally, little evidence was found for communities with populations <1,000, with the exception of two studies (Wright et al.[18] and Griffin and colleagues[14]), which conducted sensitivity analyses and indicated that per capita annual cost exceeded per capita annual benefit for small communities with <1,000 population. Cost could be even higher if the residents were remote and scattered. As Cobiac and Vos[13] showed, per capita annual cost for rural communities with <1,000 people was $24.38. Future studies should provide more evidence on the benefit and cost information of smaller communities with <1,000 people.

In terms of cost-effectiveness studies, only DALYs were used for the analysis. Future studies should provide further evidence on cost effectiveness using quality-adjusted life years (QALYs) as a measurement of effectiveness, as cost per QALY gained serves as a convenient criterion to compare economic merits of public health interventions in the U.S. Furthermore, probabilistic analysis is preferred to capture the effects of uncertainty in parameter estimates in cost or benefit analysis. Future studies should incorporate the variation in the values of cost or benefit parameter estimates either by conducting deterministic sensitivity analysis or by assigning distributions to the variables. Finally, in April 2015, DHHS adjusted the CWF recommendation to a single level of 0.7 mg of fluoride per liter of water, updating the previously recommended range (0.7–1.2 mg/L) issued in 1962 (www.hhs.gov/news/press/2015pres/04/20150427a.html). Future studies may explore the change in both the cost and the benefit of CWF following the change in recommendation.

Conclusions

Recent evidence continues to indicate that the economic benefit of CWF exceeds the intervention cost. Further, the benefit–cost ratio increases with the population of the community.

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Appendix

Supplementary data

Supplementary data associated with this article can be found at https://www.thecommunityguide.org/sites/default/files/assets/oral-ajpm-app-econ-fluoridation.pdf.