

Water Fluoridation

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Abstract

AIM: This was to present a summary of the evidence from systematic reviews of the effectiveness and safety of water fluoridation. **METHODS:** A search for relevant systematic reviews was conducted using the terms Fluoridation [Mesh] OR "water fluoridation" OR fluoridation OR (water AND fluoride) and was run from 01/01/2000 to 17/10/2008 in Pubmed, Embase, the Cochrane Database of Systematic Reviews and the Database of Abstracts of Reviews of Effects in the Cochrane Library. The quality of the systematic reviews was assessed using Scottish Intercollegiate Guideline Network (SIGN) methodology checklists for systematic reviews. Websites of guideline organisations were also searched for relevant evidence-based guidelines, which were appraised using the AGREE instrument. **RESULTS:** Of the 59 publications identified, 3 systematic reviews and 3 guidelines were included in this review. While the reviews themselves were of good methodological quality, the studies included in the reviews were generally of moderate to low quality. The results of the three reviews showed that water fluoridation is effective at reducing caries in children and adults. With the exception of dental fluorosis, no association between adverse effects and water fluoridation has been established. Water fluoridation reduces caries for all social classes, and there is some evidence that it may reduce the oral health gap between social classes. **CONCLUSION:** Water fluoridation, where technically feasible and culturally acceptable, remains a relevant and valid choice as a population measure for the prevention of dental caries.

Introduction

Rationale for this review. The use of fluoride (F) has been the cornerstone of caries preventive strategies since the middle of the 20th century. The painstaking epidemiological research in the early part of the 20th century led to the identification of naturally occurring F in drinking water as an agent with both beneficial and detrimental effects on the human dentition. Subsequent determination of the water F level that achieved an acceptable balance between the benefits (caries control) and detrimental effects (fluorosis) has been well documented [Murray et al., 1991; Burt and Eklund, 2006; Ellwood et al., 2008]. The first experimental trials of water fluoridation, i.e. the controlled addition of a F compound to a public water supply to bring its F concentration up to an optimal level to

prevent dental caries, were conducted in the USA and Canada in the mid 1940s, [Murray et al., 1991] and established water fluoridation as an effective public health measure to control dental caries. Globally, it is estimated that 350 million people drink F-water. In Europe, water fluoridation operates in the UK and Spain, and reaches approximately 10% of the population of each country [British Fluoridation Society, 2004]. The Republic of Ireland has had mandatory water fluoridation since the 1960s, and currently 71% of the Irish population receives fluoridated water [Department of Health and Children, 2002].

Over 60 years of research, including a number of systematic reviews has provided a vast body of evidence on the effectiveness and safety of water fluoridation, and the Centers for Disease Control and Prevention (CDC) included community water fluoridation as one of the ten great public health achievements of the 20th century [Centers for Disease Control and Prevention, 1999a,b]. However, in spite of its long history, and its support by numerous organisations such as the World Health Organisation, the CDC, the UK Health Departments, the Royal College of Physicians, the USA Public Health Service and many other medical and scientific organisations [British Fluoridation Society, 2004], water fluoridation has faced considerable opposition over the years. Controversy relates to: a) the risk/benefit balance of fluoridation, particularly in an era of declining caries levels and of widespread availability of alternative sources of F; b) difficulty in identifying long-term adverse effects; c) whether F is a medicine and water fluoridation is mass medication; d) the ethics of a population intervention [Cheng et al., 2007].

The aim of this paper is to present a summary of the evidence from a number of recent systematic reviews of the effectiveness and safety of water fluoridation.

Review methodology. A search was conducted to identify relevant systematic reviews on the effectiveness and safety of water fluoridation, published since the EAPD fluoride guideline in 2000 [Oulis et al., 2000]. The search terms were Fluoridation [Mesh] OR "water fluoridation" OR fluoridation OR (water AND fluorid*) and the search was run from 01/01/2000 to 17/10/2008 in Pubmed, Embase, the Cochrane Database of Systematic Reviews and the Database of Abstracts of Reviews of Effects in the Cochrane Library.

Key words: fluoridation, caries prevention, population preventive strategy

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Table 1: National Institute for Health and Clinical Excellence hierarchy of evidence for studies on the efficacy of public health interventions [NICE, 2006]. Adapted from the Scottish Intercollegiate Guidelines Network (2008).

Type and quality of evidence	
1++	High quality meta-analyses, systematic reviews of RCTs or RCTs (including cluster RCTs) with a very low risk of bias
1+	Well conducted meta-analyses, systematic reviews of RCTs or RCTs (including cluster RCTs) with a low risk of bias
1-	Meta-analyses, systematic reviews of RCTs or RCTs (including cluster RCTs) with a high risk of bias
2++	High quality systematic reviews of these types of studies, or individual, non-RCTs, case-control studies, cohort studies, controlled before/after (CBA) studies, interrupted time series (ITS) and correlation studies with a very low risk of confounding, bias or chance and a high probability that the relationship is causal.
2+	Well-conducted non-RCTs, case-control studies, cohort studies, CBA studies, ITS and correlation studies with a low risk of confounding, bias or chance and a moderate probability that the relationship is causal.
2-	Non-RCTs, case-control studies, cohort studies, CBA studies, ITS and correlation studies with a high risk – or chance – of confounding bias and a significant risk that the relationship is not causal.
3	Non-analytic studies (for example, case reports, case series)
4	Expert opinion, formal consensus

Systematic reviews were identified using the appropriate search filters in Pubmed and Embase. Only articles in the English language were considered. The quality of the systematic reviews was assessed using Scottish Intercollegiate Guideline Network (SIGN) methodology checklists for systematic reviews [Scottish Intercollegiate Guidelines Network, 2008]. An adaptation of the SIGN evidence hierarchy, which was developed by the National Institute for Health and Clinical Excellence (NICE) specifically for public health interventions [National Institute for Health Clinical Excellence, 2006], was used to grade the level of evidence (Table 1). Reviews that included more than one F modality were graded only on the quality of the studies on water fluoridation. Although the numbering system used here is no longer used by NICE, numeric grades were assigned in keeping with the overall SIGN approach adopted by the EAPD in its fluoride guideline update.

Websites of guideline organisations (NICE, SIGN, Guidelines-International-Network (G-I-N), New Zealand Guideline Group) and Health Technology organisations (SBU, National Health and Medical Research Council) and the World Health Organisation were also searched for relevant guidelines on the use of F that included water fluoridation. The quality of guidelines was assessed using the Appraisal of Guidelines for Research and Evaluation (AGREE) instrument [AGREE Collaboration, 2001].

Results

The search for systematic reviews yielded 59 publications, 8 of which were relevant. Five of these reviews [Jones et al., 1999; Demos et al., 2001; Whiting et al., 2001; Truman et al., 2002; Khan et al., 2005,] were already comprehensively covered in a well-conducted and extensive Australian systematic review [National Health and Medical Research Council, 2007] and therefore were not considered in any further detail. Thus, 3 of the 8 reviews identified formed the basis of this

review. Two of these reviews, the York review [McDonagh et al., 2000] and the Australian review [National Health and Medical Research Council, 2007], dealt with the beneficial and adverse effects of water fluoridation. The third review [Griffin et al., 2007] dealt with the effectiveness of water fluoridation at preventing caries in adults and did not consider adverse effects.

The main characteristics of the 3 systematic reviews are summarised in Table 2. Collectively, these reviews provide evidence from 244 original studies from the 1940s to 2005, and include a further 5 systematic reviews on the effectiveness and safety of water fluoridation. It is important to note that although the randomised controlled trial (RCT) is the “gold standard” design for assessing efficacy, the RCT is not always feasible for population interventions, and for water fluoridation, a prospective, comparative cohort study has been suggested as the most appropriate design for evaluating efficacy [National Health and Medical Research Council, 2007]. However, all 3 reviews found only a small number of such studies.

To allow the broadest search for evidence on potential adverse effects, studies of all levels of evidence, including cross sectional and ecological studies, were included in both the York and Australian reviews. In addition to the reviews, 2 guidelines specifically on the use of F for caries prevention [Australian Research Centre for Population Oral Health, 2006, Centers for Disease Control and Prevention, 2001] and one guideline on caries prevention in preschool children, which considered water fluoridation [Scottish Intercollegiate Guidelines Network, 2005], were also identified by the search.

Effectiveness of water fluoridation at preventing caries. The York review [McDonagh et al., 2000] included 26 studies in the analysis of the efficacy of water fluoridation. The authors concluded that the best available evidence suggests that

Table 2: Summary of characteristics of the included systematic reviews on water fluoridation.

Author, Year	No. databases searched	No. primary studies included	Inclusion criteria	Design of included studies	Level of evidence
York review [McDonagh et al., 2000]	25	214	Hierarchy of evidence (A-C) based on study design and adjustment for confounding and for measurement bias. Evaluation of effectiveness: Prospective studies comparing at least 2 populations, (F/NF), with at least 2 time points evaluated. (Studies with level of evidence A* and B) Evaluation of SES and adverse effects: Any study design comparing 2 populations (F/NF) (Studies with level of evidence A*, B or C) *No grade A studies (highest quality evidence, minimal risk of bias) were identified	102 cross sectional 47 ecological 45 before/after 13 cohort 7 case-control	2++
Australian review [NHMRC, 2007]	3	21 \diamond	Compatible with Mc Donagh et al., 2000	14 cross sectional 5 ecological 1 before/after 1 case control	2+
Griffin et al., 2007	3	9	Cross sectional studies where participants had lifetime residency in an F/NF community, or where potential confounders were controlled for in the estimate of effect of water fluoridation	8 cross sectional 1 cohort	-1

\$ Level of evidence for effectiveness. Grading by the authors, based on the National Institute for Health and Clinical Excellence hierarchy of evidence for studies on the efficacy of public health interventions [NICE, 2006] (Table 1).

\diamond This review also identified 6 systematic reviews, including Mc Donagh et al., 2000

fluoridation of drinking water supplies does reduce caries prevalence, both as measured by the proportion of children who are caries free (a median increase of 14.6%, range: -5.0 to 64%) and by the mean change in dmft/DMFT (a median reduction of 2.25 teeth, range: 0.5 to 4.4). The NNT (Number Needed to Treat) was 6, i.e. 6 people would have to drink fluoridated water for one extra person to be caries free.

The York review also considered the effect of termination of water fluoridation on caries levels. Based on 22 analyses, 14 of which showed an increase in caries in areas where fluoridation was stopped, the authors concluded that caries prevalence increases following withdrawal of water fluoridation. The Australian review [National Health and Medical Research Council, 2007], which used inclusion criteria consistent with those of York, identified 1 new systematic review [Truman et al., 2002], and 1 original before/after fluoridation cessation study [Sjöppa et al., 2000], published since the York review. The Truman review, which considered the caries-preventive effect and the economics of water fluoridation, concluded that there was strong evidence that community water fluoridation is effective in reducing the cumulative experience of dental caries within communities [Truman et al., 2002].

The cessation study by Sjöppa et al. [2000], showed no evidence of increasing caries in the previously fluoridated area. However, the Australian reviewers concluded that these additional studies did not change the findings of the York review regarding the effectiveness of water fluoridation, and stated, “the existing body of evidence strongly suggests that water fluoridation is beneficial at reducing dental caries” [National Health and Medical Research Council, 2007].

The systematic review by Griffin et al. [2007] included 9 studies that assessed the effectiveness of water fluoridation at preventing caries in adults aged 20 – 60+ yrs. The combined results of the 9 studies (7,853 participants) showed that caries levels were significantly higher in the non-fluoridated group compared with the fluoridated group (p<0.001). The prevented fraction for the 5 fluoridation studies that involved lifetime residents of fluoridated or control communities (2,530 participants), and which were published after 1979 (less heterogeneity) was 27.2% (95% CI 19.4% to 34.3%).

Table 3: Results of the systematic reviews of the effectiveness of water fluoridation

Author, Year	No./type of studies	Outcome	Conclusions
York review [McDonagh et al., 2000]	26 23 before/after 3 cohort	Median Diff in % caries free (range) 14.6% (5.0%-64%) Median Diff in dmft/DMFT (range) 2.25 (0.5-4.4) NNT 6	The best available evidence suggests that fluoridation of drinking water supplies does reduce caries prevalence, both measured by the proportion of children who are caries free, and by the mean change in dmft/DMFT. The best available evidence from studies following withdrawal of water fluoridation indicates that caries prevalence increases, approaching the level of the low-F group In studies completed after 1974, a beneficial effect of water fluoridation was still evident in spite of assumed exposure to non-water fluoride
Australian review [NHMRC, 2007]	2 1 Syst Rev 1 before/after	Results did not alter conclusion of York review	The existing body of evidence strongly suggests that water fluoridation is beneficial at reducing dental caries. The one additional original study identified since the York review did not change the conclusion of that review.
Griffin et al., 2008	9 8 cross sectional 1 cohort	Prevented Fraction (95% CI) * 27.2% (19.4 to 34.3)	These findings suggest that F prevents caries among adults of all ages

*Based on meta-analysis of 5 studies published after 1979 and with no significant heterogeneity

The York review [McDonagh et al., 2000] also explored the effect of water fluoridation over and above the effect of other sources of F, especially F-toothpaste, which has been widely used in industrialised countries from the early 1970s. Ten studies (all moderate quality) that had been published after 1974 suggested a beneficial effect of water fluoridation in spite of the assumed exposure to other sources of fluoride in the populations studied. However, the small number of studies in this analysis and their poor quality limited the confidence with which this question could be answered.

A summary of the main results from the 3 reviews relating to the effectiveness of fluoridation is presented in Table 3.

Fluoridation and Social Class. To determine whether water fluoridation results in a reduction of caries across social groups, the York review [McDonagh et al., 2000] analysed 15 studies (mostly cross-sectional, low level of evidence, all from the UK). The reviewers concluded that there appears to be some evidence that water fluoridation reduces the inequalities in dental health across social classes in 5 and 12 year olds, using the dmft/DMFT measure. The effect was not seen in the proportion of caries free children among 5 year olds. There were not sufficient data for effects in children of other ages to be investigated fully. The small quantity of studies, differences between these studies and their low quality rating suggest *caution* in interpreting these results (authors' emphasis).

Water fluoridation and adverse effects

Both the York and Australian reviews considered the adverse effects of water fluoridation under the headings fluorosis, bone fractures, cancer and other adverse effects. Fluorosis was by far the most common adverse effect reported. Most of the studies included in these analyses were of low quality (cross-sectional and ecological studies).

Fluorosis. Based on the analysis of 88 studies, the York review [McDonagh et al., 2000] concluded that there is a dose-response relationship between water-F level and the prevalence of fluorosis. The estimated proportion of the population with any fluorosis at different water-F levels ranged from 15% (95% CI 10-22) at a level of 0.1 ppm F to 72% (95% CI 62-80) at a level of 4 ppm F. At water levels of 1ppm F, the prevalence of any fluorosis was 48% (95% CI 40 -57) and the prevalence of fluorosis of aesthetic concern (defined as TF \geq 3 or Dean's Mild or higher or TSIF \geq 2) was 12.5% (95% CI 7.0 to 21.5%). The number of people that would need to be exposed to water levels of 1 ppm F for one additional person to develop fluorosis of any level was 6 (95% CI 4 to 21) compared with a theoretical low level of 0.4 ppm F. The authors commented that within the reviewed studies, efforts to control for the effects of potential confounding factors, or reducing potential observer bias were uncommon.

The Australian review [National Health and Medical Research Council, 2007] identified an additional systematic review, graded as poor methodological quality [Khan et al., 2005]

which reported an increase in the prevalence of fluorosis with increasing water-F concentration: 17% at 0 to <0.3 ppm F, 27% at >0.3 to <0.7 ppm F and 32% at >0.7 to <1.4 ppm F. The Australian reviewers also identified 10 additional cross sectional studies on fluorosis and water-F published since the York review. With the exception of 2 studies – one from China and the other from South Africa – the prevalence of fluorosis of aesthetic concern at water levels of 0.8-1ppm F did not exceed 7%. They completed a meta-analysis of the 10 additional studies (although there was significant heterogeneity among them) and found a pooled relative risk of 2.54 (95% CI 1.52-3.56, $p < 0.001$) of developing any fluorosis at water fluoride levels of 0.8 – 1.2 ppm F, compared with levels of ≤ 0.4 ppm F. The pooled relative risk for developing fluorosis of aesthetic concern was 4.01 (95% CI 3.15-5.10, $p < 0.001$, low heterogeneity). The conclusion of the Australian review was that while there is a 4-fold risk of developing fluorosis of aesthetic concern with optimal versus suboptimal water fluoridation, the absolute increase in prevalence is small (approximately 4-5%).

Bone Fracture. The York review analysed 29 studies and found no clear association between bone fracture and water fluoridation. The Australian review identified 2 new relevant systematic reviews [Jones et al., 1999; Demos et al., 2001], the results of which concurred with the York review, that water fluoridation at levels aimed at preventing caries has little effect on fracture risk – either protective or deleterious.

The results of three subsequent original studies included in the Australian review did not alter this conclusion. The findings of the 3 studies were inconsistent, with one study finding no association between water fluoride level and prevalence of bone fracture [Sowers et al., 2005], one study finding a significant increase in the prevalence of bone fracture at water fluoride levels of 1.51-8.49 mg/L but not at higher levels up to 16mg/L [Alarcon-Herrera et al., 2001] and the third study finding a significant increase in the prevalence of bone fractures both at low F levels (0.25 -0.34 ppm F) and at high fluoride levels (4.32 -7.97) [Li et al., 2001]. In all 3 studies, the reference water fluoride level was <1.5 ppm F.

Cancer. The York review included 26 studies that examined the relationship between water fluoridation and cancers. Overall, no clear association between water fluoridation and incidence of or mortality from bone cancers, thyroid cancer or all cancers was found.

The Australian review identified 4 additional original studies (3 ecological, 1 case-control). Of the 3 ecological studies 2 were of low quality, did not control for potential confounders, and found conflicting results. The study by Takahashi et al. [2001] found results that suggested an association between water fluoridation and increased cancer incidence in 23 of the 36 bodily sites investigated and between fluoridation and decreased cancer incidence in 4 sites. In the remaining 9 sites there was no significant association. The second

ecological study suggested that F concentration in drinking water was inversely correlated with cancer incidence ($r = -0.75$, i.e. lower F, higher cancer incidence) [Steiner, 2002]. The third ecological study found that cancer mortality rates for males and females were generally similar between the 10 non-fluoridated and 10 naturally fluoridated (<0.28 ppm F) municipalities studied. The only significant finding was for bladder cancer mortality, which was significantly higher among females in naturally fluoridated areas. In the absence of biological reasoning, the authors of the study suggested that this was a chance finding as a function of the large number of comparisons [Yang et al., 2000].

The one case-control study, which was graded as fair/good quality, compared F exposure of histologically confirmed osteosarcoma cases aged < 20 years ($n=103$), with that of matched controls ($n=215$) [Bassin et al., 2006]. The study was a subset of patients from a larger, ongoing case-control study – the Harvard Fluoride Osteosarcoma study. After adjusting for potential confounding factors e.g. income by postal/zip code, county population, use of bottled or well water, age, and any use of self-administered F products, the results of the study suggested an increased risk of osteosarcoma among young males (but not among females) with water fluoridation. The authors of the Australian review draw attention to a response letter to the Bassin study by the co-investigators of the Harvard Fluoride Osteosarcoma study. The authors of the letter advised readers to be especially cautious in interpreting the results of the Bassin study, as the results of the second set of cases of the Harvard study has not replicated those of the first set analysed by Bassin. They advised waiting for the publications from the full study before drawing conclusions [Douglass and Joshipura, 2006].

Other effects. The York review analysed 25 studies with a wide variety of outcomes, including Alzheimer's disease, impaired mental functioning, dementia, cognitive impairment, Down's syndrome, congenital malformations, mortality, infant mortality, IQ/mental retardation, anaemia during pregnancy, age at menarche, Sudden Infant Death syndrome, skeletal fluorosis and goitre. There was insufficient evidence on any particular outcome to reach a conclusion. The Australian review identified one systematic review of the association of Down's syndrome and water-F level [Whiting et al., 2001], which concluded that the evidence of an association between the 2 variables was weak, and that all identified studies were of poor quality. The 3 additional original studies identified by the Australian reviewers did not suggest an increased risk of other adverse events at a fluoridation level of approximately 1 ppm F [National Health and Medical Research Council, 2007].

Guidelines incorporating recommendations on the use of water fluoridation

Two guidelines were identified which included recommendations regarding water fluoridation. These guidelines came from countries with extensive water fluoridation – the USA [Centers for Disease Control and Prevention, 2001] and Australia [Australian Research Centre for Population Oral Health, 2006]. Both guidelines were developed by expert working groups, and both fell short of AGREE criteria in their rigour of development, although the CDC guideline was better in this domain than the Australian guideline. Both guidelines recommended the continuation and extension of water fluoridation in their countries, as a safe, effective, efficient and socially equitable approach to the prevention of caries. The guidelines also included recommendations on the appropriate use of topical F in the context of a fluoridated population. A third high quality guideline on the prevention and management of caries in preschool children, considered the evidence of benefits and adverse effects reported in the York review as it applied to the Scottish population. This guideline made a research recommendation that a robust evaluation of the benefits as well as the potential risks of fluorosis, in the current environment in Scotland should be a health priority [Scottish Intercollegiate Guidelines Network, 2005].

Discussion

The 3 systematic reviews included in this paper constitute the most rigorous analysis of the best available evidence on the effectiveness and safety of water fluoridation. Assessing the quality and strength of evidence is an essential step in guideline development. Many grading systems exist, and the EAPD has chosen to use the SIGN system for updating its guidelines on the use of F in children. While this system works well for individual level interventions, its application is more problematic when it comes to public health interventions such as water fluoridation because most of the study designs included in the reviews, such as controlled before/after studies and cross-sectional studies are not included in the hierarchy of evidence. The specific grading system for public health interventions used in this paper was an adaptation of the SIGN hierarchy and yet still did not cover the full range of studies included in the reviews, as there is no grading for a systematic review of cross sectional studies.

For any intervention, the key questions that must be addressed are:

- Does it work?
- Is it safe?
- What is the risk/benefit balance?
- Is it acceptable to the target population?

The importance of these questions is amplified when applied to a population intervention, such as water fluoridation. While evidence on effectiveness and safety is provided from

systematic reviews, questions relating to the risk/benefit balance, acceptability, feasibility, cost, structural and legal issues are population-specific and can only be addressed by informed decision-makers for that specific population.

The 3 systematic reviews found that water fluoridation was effective at reducing caries in children [McDonagh et al., 2000, National Health and Medical Research Council, 2007] and adults [Griffin et al., 2007]. The evidence of effectiveness in adults, although based on cross sectional rather than prospective studies, demonstrates the lifelong benefit of water fluoridation. This is of huge public health importance as people are retaining their teeth into old age. The lifelong benefits are an important consideration when reviewing the effectiveness of water fluoridation for children, because an intervention that confers benefit beyond childhood is preferable to one with benefits to childhood only.

The finding that water fluoridation has a beneficial effect in the presence of other sources of F [McDonagh et al., 2000] is also of particular relevance in the 21st century. The widespread use of F toothpaste has occurred, and is supported by a Cochrane systematic review on topical F, which found that the use of topical F may provide additional caries reduction in subjects from fluoridated areas [Marinho et al., 2003].

As a population preventive strategy, water fluoridation is unmatched in its ability to reach all sectors of society, including those who are least likely to avail of other sources of fluoride or to access regular dental care. The York review [McDonagh et al., 2000] concluded that water fluoridation seems to reduce inequalities in children's dental health across social classes in 5 and 12 year olds. Further research in this area has shown that water fluoridation benefits all social strata, and supports the York review finding that it may reduce inequalities in oral health, [Burt, 2002; Medical Research Council, 2002] which is seen as one of fluoridation's greatest strengths.

The York and Australian reviews confirmed that fluorosis is the most commonly reported adverse effect associated with water fluoridation. Both reviews found a significant association between water fluoride levels of 0.8-1ppm F and fluorosis of aesthetic concern, although few of the included studies controlled for confounding factors. Dental fluorosis is an indicator of total F ingestion during tooth development and there are now many sources of F available, which contribute to the risk of developing fluorosis.

The question of the caries prevention/fluorosis risk balance with water fluoridation is one that has received considerable attention in those countries with established water fluoridation programs, particularly in light of declining caries levels and increasing prevalence of fluorosis [Centers for Disease Control and Prevention, 2001; Department of Health and Children, 2002; Australian Research Centre for Population Oral Health, 2006; Health Canada, 2008]. In Ireland, the decline in caries between 1984 and 2002 among children and

adolescents was accompanied by an increase in the prevalence of fluorosis, mainly in the Questionable and Very Mild categories [Whelton et al., 2004]. The Forum on Fluoridation, which was established by the Minister for Health to review water fluoridation in Ireland, recommended that water fluoridation should continue as a public health measure, but that the water-F level should be reduced from 0.8-1 ppm F to 0.6-0.8 ppm F, with a target of 0.7 ppm F. The necessary legislative amendment was enacted in 2007. Recommendations on the home use of toothpaste were also issued to discourage toothpaste use before the age of 2 years [Department of Health and Children, 2002]. Canada has taken a similar approach to Ireland, in recommending 0.7 ppm F as the optimal target concentration of F in drinking water, but recommended the use of low F-toothpaste for children and reduction in the F content of infant formula [Health Canada, 2008]. In Australia, where 76% of the population has fluoridated water, the response to increasing fluorosis prevalence noted during the 1990s was to continue water fluoridation at the same level and to control exposure of young children to other F sources by discouraging toothpaste use below the age of 24 months, encouraging the use of low F-toothpaste (400-550 ppm F) under age 7 and reducing the F content of infant formula. The result of these measures was a substantial reduction in the prevalence of fluorosis [Riordan, 2002; Do and Spencer, 2007], without any apparent increase in dental caries [Riordan, 2002].

With the exception of dental fluorosis, for which a clear dose/response relationship was identified, there was considerable uncertainty in answering questions relating to safety due to the poor quality of the included studies. Both the York and Australian reviews failed to find any association between water fluoridation and bone fracture or cancer. The future publication of the results of the main Harvard Fluoride Osteosarcoma Study should clarify the uncertainty around the relationship between water fluoride levels and osteosarcoma suggested by Bassin et al. [2006].

With regard to other potential adverse effects, the evidence was too limited to allow confident conclusions to be made. While updated analysis of ecological data on fluoridation and cancer is recommended, further research on other adverse effects is not considered a priority [Medical Research Council, 2002]. The recent development of new guidelines for Strengthening the Reporting of Observational Studies (STROBE) [von Elm et al., 2007] should go a long way to improving the reporting of, and ultimately the quality of, evidence from future observational studies on water fluoridation.

In Europe, Council directive 98/83/EC on the quality of water for human consumption sets an upper limit of 1.5 mg/l for the F content of drinking water in member states. The upper limit for the F content of natural mineral and spring waters is covered by separate legislation (Commission Directive 2003/40/EC) and is set at 5 mg/l. Natural mineral and spring

waters containing more than 1.5 mg/l are required to carry the label "contains more than 1.5 mg/l F: not suitable for regular consumption by infants and children under 7 years of age" and also to give an indication as to the actual fluoride content. Commercial bottled water is commonly consumed by Europeans and should be taken into account when estimating fluoride intake from drinking water.

Conclusions

The best available evidence suggests that water fluoridation is an effective and safe community-based intervention for preventing caries. Although there may be a perception that the caries problem has been resolved in industrialised countries, any disease affecting over 75% of the population by age 15 in an established market economy [Whelton et al., 2006] remains a major public health problem, particularly for those who are disadvantaged and bear the greatest burden of disease. Water fluoridation, where technically feasible and culturally acceptable, remains a relevant and valid choice as a population measure for the prevention of dental caries.

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