

Water fluoridation and oral health

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Water fluoridation, is the controlled addition of fluoride to the water supply, with the aim of reducing the prevalence of dental caries. Current estimates suggest that approximately 370 million people in 27 countries consume fluoridated water, with an additional 50 million consuming water in which fluoride is naturally occurring. A pre-eruptive effect of fluoride exists in reducing caries levels in pit and fissure surfaces of permanent teeth and fluoride concentrated in plaque and saliva inhibits the demineralisation of sound enamel and enhances the remineralisation of demineralised enamel. A large number of studies conducted worldwide demonstrate the effectiveness of water fluoridation. Objections to water fluoridation have been raised since its inception and centre mainly on safety and autonomy. Systematic reviews of the safety and efficacy of water fluoridation attest to its safety and efficacy; dental fluorosis identified as the only adverse outcome. **Conclusion:** Water fluoridation is an effective safe means of preventing dental caries, reaching all populations, irrespective of the presence of other dental services. Regular monitoring of dental caries and fluorosis is essential particularly with the lifelong challenge which dental caries presents.

Key words: Water fluoridation, Effectiveness, Dental caries, Fluorosis.

Introduction

Dental Caries (tooth decay); a transmissible infectious disease with a multifactorial aetiology has affected individuals for centuries at least since the seventh century and the Iron Age (1). Change in the distribution of dental caries intra-orally has occurred, as has the dominant paradigm in managing dental caries. A much greater emphasis is now being encouraged towards prevention rather than curative care. Community factors are currently the focus of considerable research internationally. Social gradients in caries are demonstrated and neighbour-

hood factors such as where we live and the foods and the fluorides we have access to, all exert an impact on the development of the disease (2). Dental caries is still a major oral health problem in many established economies, affecting 60-90% of schoolchildren and the vast majority of adults. It is also a prevalent oral disease in several Asian and Latin-American countries, while it appears to be less common and less severe in many African countries (3). In the US it has been described as the most common chronic disease of childhood (4). Untreated dental caries can lead to pain, infection, impaired

function, poor aesthetics, and diminished quality of life, which equate to a significant human, financial, psychological and emotional cost.

Water fluoridation is described as the controlled addition of fluoride to the water supply with the aim of reducing the prevalence of dental caries. Fluoride can also occur naturally in some water supplies. Current estimates are that 370 million people in 27 countries are currently supplied with artificially fluoridated water and 50 million around the world are drinking naturally fluoridated water (5).

This paper will discuss water fluoridation under the following headings: Background, the mode of action, the effectiveness, the risks and benefits, the monitoring of water fluoridation and the legislative nature of providing communities with water fluoridation.

In the review baseline and subsequent national oral health surveys conducted in Ireland are included to demonstrate the effectiveness of water fluoridation and the challenges to water fluoridation; in the Republic of Ireland (RoI) 73% of the population presently benefit from water fluoridation. Thus providing an appropriate example for Europe (6, 7, 8).

The terms part per million, ppm and mg/l are used rather than the SI unit for fluoride in water $\mu\text{g/ml}$, to conform to previous research.

Background

Water fluoridation is an ideal public health measure in reducing dental caries; since its effectiveness does not require conscious daily cooperation from individuals (9) The beneficial effects of natural water fluoridation in caries prevention was identified in the first part of the 20th century and is undoubtedly a significant landmark in dentistry (10, 11, 12), culminating in the introduction of artificial water fluoridation to the

pioneering public health city of Grand Rapids, Michigan (13). In the second part of the 20th century, to address the high prevalence of dental caries water fluoridation was introduced to many countries, including Ireland, Australia, Hong Kong, Israel, New Zealand, Singapore, and the UK.

Mode of Action

The mode of action of fluoride in the prevention of dental caries is predominantly post-eruptive; however, the pre-eruptive effect of ingested fluoride is also important. Findings from Australia, the Netherlands and Maryland support the pre-eruptive effect of fluoride in reducing caries levels in pit and fissure surfaces of permanent teeth. Research has also indicated that exposure to fluoridated water from birth produces the maximum benefit (14, 15). What is clear is that a constant low level of fluoride ion in saliva and plaque fluid reduces the rates of enamel demineralisation during the caries process and promotes the remineralisation of early caries lesions (16, 17). Fluoride concentrated in plaque and saliva inhibits the demineralisation of sound enamel and enhances the remineralisation of demineralised enamel.

The effectiveness of water fluoridation

The Centers for Disease Control and Prevention (CDC) have recognised water fluoridation as one of the ten great public health measures of the twentieth century (12). The extensive international research demonstrating the effectiveness of water fluoridation is summarised in a number of important texts (18, 19), recently Rugg-Gunn and Do (20) presented the international studies attesting to the effectiveness water fluoridation published between 1990 and 2010, the reader is referred to these sources for a review of the many international studies. The number of studies which were conducted

since 1990 has declined; newer studies have tended to be pragmatic with the statistical analyses taking account of confounding factors (20, 21). Despite an overall reduction in the number of countries and studies represented the number of studies from Brazil and Australia had increased, both countries having extensive water fluoridation (5, 20). All studies demonstrate a similar positive reduction in per cent caries reduction.

Sources suggest that water fluoridation is not only effective in childhood but also into adulthood (22, 23). Water fluoridation combined with toothpaste use could be more effective than either alone (24).

Water fluoridation in Ireland

The fluoridation of water supplies in Ireland is indicative of the effectiveness, the benefits of, the required monitoring and challenges that may occur after implementation (25). In the mid twentieth century the RoI required a solution to the effects of widespread dental caries and introduced water fluoridation to Dublin on July 15th 1964, and to Cork in May 1965 the planned introduction being delayed by some four years due to legal challenges in both the High and Supreme Courts (26). By 1970 the majority of cities and larger towns were fluoridated. Under the legislation directing water fluoridation (27) provision was made that, before

implementation of the Act a baseline survey of caries levels among children and adolescents would be undertaken (6). The Act also importantly stipulated that regular caries surveys be undertaken “whenever and as often as the Minister requires” to monitor the effectiveness of fluoridation of water supplies in controlling dental caries.

The baseline surveys conducted prior to water fluoridation indicate a high caries experience; this was recorded as the number of teeth which were decayed, missing or filled because of tooth decay. They were recorded using the dmf/DMF index for both the primary (baby teeth) (dmf), and permanent (adult) (DMF) dentitions in 5-year-old to 15-year-old children (6, 28) (Table 1). Once the fluoridation of water supplies commenced the concentration of fluoride in water was set in the range 0.8 to 1.0 ppm, with a target of 0.9 ppm.

National survey of children’s oral health (Republic of Ireland) – 1983-84

In 1982 the Department of Health in the RoI commissioned a National Survey of Children’s Dental Health, the primary aim of which was to measure the effectiveness of water fluoridation on a countrywide basis, it was also decided that levels of enamel fluorosis would be recorded, using internationally accepted indices (28, 29). Random sam-

Table 1 Mean dmft* in five-year-olds, and DMFT* in 15-year-olds, in fluoridated communities (full FI) in the Republic of Ireland in 1984 and 2002, and in non-fluoridated communities (non FI) in the Republic of Ireland and Northern Ireland in the 1960s, 1983-84 and 2002 (6, 7, 8)

Year	5-Year-Olds			15-Year-Olds		
	Full FI	Non FI		Full FI	Non FI	
	RoI	RoI	NI	RoI	RoI	NI
1960	-	5.6	4.8	-	8.2	10.6
1983 – 1984	1.8	3.0	4.5	4.1	5.4	9.2
2002	1.3	1.7	1.8	2.1	3.2	3.6

FI = fluoridated; RoI = Republic of Ireland; NI = Northern Ireland; dmf = decayed missing filled primary (teeth). DMF refers to permanent teeth.

ples of children who were lifetime residents of either fluoridated or non-fluoridated areas and aged five, eight, 12 or 15 years-old were examined by 10 examiner/recorder teams (7). The criteria adopted for dental caries examination were similar to those used in the baseline studies of 1961-1963 (6) thus permitting comparison. The results indicated a decline in caries levels for children in both fluoridated and non-fluoridated areas; the decline being considerably greater in fluoridated areas, fluorosis was measured using Dean's index of fluorosis, the teeth scored for fluorosis were the upper permanent incisors (29). The children who were resident in non-fluoridated areas had a significantly higher dmft/ DMF than those in fluoridated areas (Table 1).

The observed downward trend in dental caries has been noted in many international studies; the advent of fluoridated toothpastes in the 1970's providing a valued contribution (30). In the national survey in 1983-'84 (7) the prevalence of fluorosis was low, with 94% of children in fully fluoridated communities having normal enamel according to Dean's Index (29), compared with 98% among eight-year-old children in non-fluoridated communities (Table 2). Only fluorosis grades of 'questionable' and 'very mild' were recorded in the survey (7, 8, 31).

The North south survey of children's oral health – 2002

In 2000 under a contract for the evaluation of oral health services the Department of Health commissioned a further national survey of children's dental health, with the aim of monitoring the effectiveness of water fluoridation (8). The study included a contemporaneous survey of children's dental health in Northern Ireland (NI), where water fluoridation has not been introduced (31). The diagnostic criteria for both caries and dental fluorosis were the same as used in the 1984 study (7). It was seen that in the period from 1983-1984 to 2002 there was a substantial reduction in dental caries in both fluoridated and non-fluoridated communities in the RoI, and in the non-fluoridated population of NI; the reduction in the period from 1983-'84 to 2002, is greater in fluoridated communities. In the five-year-old age group, the mean dmft among the lifetime residents of fluoridated communities in the RoI declined from 1.8 in 1983-'84 to 1.3 in 2002, the corresponding figures for five-year-old children in non-fluoridated areas in the RoI were 3.0 and 1.7, and in NI were 4.5 and 1.8 respectively. Similar trends are apparent in the figures recorded for caries among 15-year-olds in both jurisdictions (Table 1).

Table 2 Dean's Index of Fluorosis*- % of eight-year-olds affected according to fluoridation status in the Republic of Ireland and Northern Ireland in 2002 and 1984 (7, 8)

Eight-Year-Olds	Full FI	Non FI	Full FI	Non FI	Non FI
	RoI	RoI	RoI	RoI	NI
	1984 (a)	1984 (b)	2002 (c)	2002 (d)	2002 (e)
Normal	94	98	76	90	90
Questionable	5	2	11	7	6
Very Mild	1	0	8	2	3
Mild	0	0	4	0	0
Moderate	0	0	0	0	0
Severe	0	0	0	0	0

*Scores relate to permanent maxillary incisor teeth; RoI= Republic of Ireland; NI= Northern Ireland; The difference between a and c, c and d and c and e were significant (p<0.0001).

The inverse occurred with the prevalence of dental fluorosis and fluorosis increased in the RoI between 1983-1984 and 2002, particularly in residents of communities with water fluoridation. In 1983-'84, ninety-four percent of children residing in fluoridated communities in the RoI had normal enamel; this figure had reduced to 76% in 2002 (Table 2). The figures for 'questionable', 'very mild' and 'mild' fluorosis in 1983-1984 were 5%, 1% and zero, respectively; these figures had increased in 2002 to 11%, 8% and 4%, respectively. The increasing prevalence of fluorosis was also identified internationally (32, 33).

The benefit of water fluoridation

Water fluoridation has been the subject of rigorous reviews of late and has been recognised as safe and as the most effective method of reaching the whole population irrespective of access to dental services in this way each individual can benefit without the need for active participation (24, 34, 35). In addition the review of McDonagh et al. (24) suggested water fluoridation conferred a benefit over and above the use of fluoride containing toothpastes alone. The process of water fluoridation has been endorsed by the world's leading science and health organisations including the WHO (36), IADR (International Association of Dental Research) and FDI (World Dental Federation), with the benefits available to both child and adult (22, 23). Griffin et al. (37) showed that for the US water fluoridation delivered significant cost savings.

The risk of water fluoridation

Dental fluorosis is recognised as a consequence of consuming fluoridated water supplies.

It arises as a result of a long-term intake of fluoride during the preeruptive develop-

ment of teeth. It is a hypomineralisation of enamel characterised by an increased surface and subsurface porosity causing opacity, pitting or staining of the enamel (38).

However water fluoridation since its initiation has attracted hostile publicity, those who do not put a value on water fluoridation caution that it is; costly and not effective, that it impacts negatively on general health; causes objectionable dental fluorosis and that it is a violation of medical ethics and the rights of the individual (39). Thus the very core of its capacity to promote prevention to the whole population is challenged.

All of the reviews conducted on water fluoridation have acknowledged that fluorosis occurs to some degree with water fluoridation, and fluorosis was identified as the only adverse effect of fluoridation (33). The likelihood of fluorosis occurring was identified at the very outset, for it was McKay's observation of the Colorado 'brown stain' that led to the identification of the beneficial effect of fluoride in the prevention of dental caries and was acknowledged in the work of Dean and the '21 cities study' (10). The environmental concerns which have been raised with regard to fluoride were recently addressed in the report of the European Commission's Scientific Committee on Health and Environmental Risks (SCHER) (40). The committee did not identify any evidence of negative environmental impacts from community water fluoridation. Ethical concerns were addressed by the Nuffield Council on Bioethics (41, 42, 43). Reviews conducted in the US, Australia, and Canada arrived at similar conclusions (35, 44, 45). Nevertheless it is crucial that on-going surveillance of general health be maintained in fluoridated and non-fluoridated communities. The structured use of health registers, for example cancer and hip fracture registers, are an important source of information for this purpose.

Monitoring

The studies conducted in Ireland (7, 8) established there was a decline in dental caries after the fluoridation of water supplies and also an increase in dental fluorosis. Good practice recommends the recording of the fluoride concentration in water supplies on a regular basis, daily, weekly, monthly and strategies must be in place to notify the relevant authorities of the measurements that are recorded. Audit is possible when the agency fluoridating supplies is not the same agency. In Ireland the sanitary authorities have responsibility for the addition of fluoride to water supplies while the health authorities and environmental protection agency have responsibility for monitoring the concentration of fluoride in supplies (26, 46). This also ensures agencies are compliant with legislation and regulation.

Regular monitoring has led to changes in fluoride concentration internationally. When the prevalence and severity of fluorosis between the two national surveys (7, 8) was compared in Ireland (7, 8), (Table 2), the prevalence had increased. Consequent on these findings in 2007 the level of fluoride in drinking water was reduced from a range of 0.8 to 1.0 ppm, with a target of 0.9 ppm, to a range of 0.6 to 0.8 ppm, with a target of 0.7 ppm (47). In addition, recommendations for the use of fluoride toothpaste by infants and young children were also introduced (34). Recommendations with regard to toothpaste were made as the inappropriate use of fluoride toothpaste in young children who may not be able to expectorate it adequately is a major risk factor in fluorosis (38, 48, 49).

A downward revision of the concentration of fluoride in water supplies has occurred in other jurisdictions to balance the availability of fluorides from other sources, such as fluoridated toothpastes. The Department of Health and Human Services in the US has recommended water fluoridation at

0.7 mg/l (ppm), rather than the previous range 0.7 mg/l – 1.2 mg/l, (ppm) to take account of other sources from which communities may receive fluorides (50). In Canada the concentration of 0.7 mg/l (ppm) of fluoride has been set moving from the previous range of 0.8 to 1.0 mg/l (ppm) (51) while in Australia, levels have remained unchanged, since the current research in Australia into caries prevention and fluorosis suggests maintaining the status quo. Some Asian, tropical and sub-tropical regions have reviewed the concentrations at which water is fluoridated and have agreed an upper and lower limit of 1mg/l and 0.5 mg/l (ppm) respectively.

Naturally occurring high fluoride water supplies occur around the world and defluoridation if required is possible (18), some of the methods which can be used for defluoridation are to blend waters with high fluoride concentration with waters of low concentration in addition technologies such as reverse osmosis, electro dialysis and distillation are available in the market. The fluoridation plants must have an effective fail-safe system with well-defined limits for the precision of measurements (52). A concentration of 1.5mg/l (1.5 ppm) is accepted as the Maximum Acceptable Concentration (MAC) of artificially fluoridated supplies.

Legislation

Legislation providing for water fluoridation can be of two types. It may be mandatory, requiring a ministry of health or communities of a certain size to fluoridate their public water supplies if it is below the accepted fluoride level; this is the type of legislation in Ireland. Alternatively, it may be of the permissive or enabling type, empowering the ministry of health or a local government to institute fluoridation. Some countries and jurisdictions require consultations with the community and to consider such consultations prior to proceeding, such as in the UK.

Discussion

In this article the authors have brought together the experience of and the challenges to water fluoridation using the experiences in the RoI for examples. They have also considered why it remains an effective component of prevention and oral health policy. Emerging evidence suggests that the declining caries levels which excited oral health professionals through the nineties and early 2000's may have plateaued. Internationally established economies are tending towards a more energy dense, refined carbohydrate diet, which may become more challenging in the delicate balance in preventing dental caries and dental fluorosis, and promoting oral health. The National Health and Medical Research Council in Australia (35) concluded: the existing body of evidence strongly suggests that water fluoridation is beneficial at reducing dental caries'. For most studies the consistent measure of effect to indicate the effectiveness of water fluoridation is the dmf/DMFT index (20), scientifically this makes sense and permits comparison with relative ease. Perhaps going forward ways of demonstrating effectiveness in terms of the distress and misery avoided, capturing children's ability to develop a positive association with oral health should be considered. The emotional impact of dental caries is significant and apparent on a daily basis to a significant number of families and dental personnel.

Conclusion

Water fluoridation is an effective safe means of preventing dental caries, reaching all populations, irrespective of the presence of other dental services. The monitoring of dental caries and dental fluorosis is the cornerstone of good public health practice and is essential particularly when the lifelong challenge which dental caries presents is considered.

Future research must consider the challenges in reporting appropriate outcomes for both dental caries and dental fluorosis and the means of overcoming the challenges in the design, conduct and reporting of future work.

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