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100 Years of Fluoride in Water: A Review

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ABSTRACT

Fluoridation of water has been controversial. Water fluoridation has recently been considered as a health hazard particularly in view of the decline in dental caries in the Western World. Fluoridation of water, the only whole population strategy, can reduce the disease levels in all, including those in the high-risk individuals and reduce dental health inequalities. It is also a cost-effective method; however, in the highly industrialized countries, one must consider the opportunity costs involving seeking people's opinion, legal issues, promotion, etc. apart from the actual costs. This article reviews the arguments for and against water fluoridation.

Keywords: Water fluoridation, Systemic fluorides, Topical fluorides, Fluoride toxicity, Mottling, fluorosis

Abbreviations: CDC: Centre or Disease Control; COMA: Committee of Medical Aspects of Food Policy; dmft/DMFT: Decayed, missing, filled teeth; ppm: Parts Per Million; UK: United Kingdom; USA: United States of America

INTRODUCTION

A bridge between the 'fluoridation' and 'anti-fluoridation' worlds seems unlikely as much water has flown below it! By 1916, it became evident to Frederick McKay that a mysterious element in water led to the menace, "mottling" of teeth [1]. Subsequently Dean and his co-workers accidentally discovered the preventive benefits of fluoride in water [2]. During the last half of the 20th century water fluoridation and subsequently, topical fluorides became increasingly available as public health measures for the prevention of dental caries [3]. Fluoride in water became a bidirectional sword with the effects on health apparent; a cost to be paid for preventing tooth decay and voices were raised against its presence in water as a whole population approach [4]. Beyond 2000, withdrawal of fluoridation or lowering the level of fluoride in the drinking water was offered as solutions; particularly in populations with decline in dental caries. In a recently published research, almost 100 years after the McKay's report, research [5] reported a reversal of trend, i.e. increase in dental caries upon the cessation of water fluoridation, thus reconfirming that the mystery and controversy with the fluoride in the water continues.

A substantial reduction in dental caries has been observed in the second half of 20th century in highly industrialized countries [6]. Researchers have attributed this caries reduction to the widespread use of fluorides [7]. Water fluoridation was the first public health intervention for caries prevention that yielded obvious and tangible benefits [3]. The Centre for Disease Control (CDC) in the USA identified water fluoridation as one of the ten best public health interventions of the 20th century [8]. The World Health Organization (WHO) endorsed fluoridation of water as a strategy for the prevention of dental caries [9] and in a recent publication, WHO advocated "establishment of national plans for use of fluoride based on appropriate programmes for automatic administration of fluoride through drinking water, salt or milk, or topical use of fluoride such as affordable toothpaste" [10]. However, water fluoridation, has been a controversial issue ever since its inception [11].

Evolution and current status of water fluoridation in the world

In 1942, Dean and his co-workers reported a strong association between dental caries and fluoride level of 1 ppm in water in their classical epidemiological investigation, the 21-city study, in the USA; wherein, in individuals residing in areas with 1 ppm level of fluoride in water, 50 % reduction in dental caries was observed [12]. They also reported that at this level of fluoride in water, only mildest forms of dental

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fluorosis with no aesthetic concern were seen occasionally [3]. However, these studies of Dean and his co-workers, being purely observational, could establish only association and no causation; hence interventional studies were needed to explore the effect or artificially fluoridating water supplies on dental caries experience of people [12]. The three studies in the USA over next 15 years: Grand Rapids - Muskegon study, Newburgh - Kingston study and Evanston - Oak Park study provided the experimental evidence that at 1 ppm water fluoride level, up to 50% reduction in caries experience was demonstrable [3]. The concept of "optimal fluoride level" in water (with maximal caries reduction benefits and "negligible biologic [aesthetic] significance") was put forth later by Hodge in 1950; and it was also postulated that 1ppm level of fluoride level in water resulted in a more perfectly crystallized enamel [12]. Thus, it led to a belief that fluoride needs to be ingested for its anti-caries action (the pre-eruptive effects), until the post-eruptive effects of fluoride came to light in later years [12].

Water fluoridation attracted immediate acceptance due to low per capita cost (as low as 51 cents per person per year in 1989 in an existing system) and being a whole population strategy [13]. Approximately 5.7 % of the world population receives fluoridated water [14]. By 1989, 34 countries-initiated fluoridation programmes [13]. The highest number of people (just under 60% of the population) drinking fluoridated water lives in the US [12,14]. In Brazil and Ireland, fluoridation was made mandatory [12]. Artificial water fluoridation was also introduced in England, Ireland, and Spain, Australia, Chile, Colombia, Canada, Hong Kong, Singapore, Israel, Malaysia and New Zealand [12,14]. In England, fluoridation programmes began in 1960s, but were halted after meeting with a lot of resistance since inception [11]. Approximately 5 million people in England consume artificially fluoridated water in England; mainly the West Midlands, Yorkshire and Tyneside [14]. After 2005, with renewed interest of the government, it is being reintroduced in South Central region after consulting people groups [11]. A few countries have withdrawn the fluoridation schemes such as Germany, Finland, Japan, the Netherlands, Sweden and Switzerland, however, the rationale for the same is not clear except in Switzerland where the reason cited was that "other measures being of 'comparable effectiveness' to compulsory medication" [14].

Controversies related to water fluoridation as a public health strategy

As stated previously, fluoridation has been a controversial issue even before its implementation. Armfield [15] reported that fluoridation, unlike other public health issues such as chlorination of water, ban on smoking in public places, mandatory seat belt use, etc. attracted unnecessary political attention and public criticism. Safety and toxicity in terms of dental fluorosis and overall health concerns, evidence-base for effectiveness particularly in view of the reduction in caries over past few decades in highly industrialized countries, ethical and legal considerations related to implementation of water fluoridation policies, and a few other controversial issues are discussed below.

A comprehensive review of the literature on water fluoridation, the York review concluded that fluoridation increased the population of caries free children by 15% and reduced the mean dmft/DMFT by 2,25; furthermore, the reduction was of a higher magnitude in case of a higher baseline caries level (The NHS Centre for Reviews and Dissemination) [16]. A more recent review reported by Australian National Health and Medical Research Council [17] also concluded the benefits of water fluoridation in terms of caries reduction and recommended fluoridation of water in the range of 0.6-1. ppm depending on the climatic conditions, to balance reduction of dental caries and risk of dental fluorosis. According to the York review, 13% of children in fluoridated areas had dental effects of aesthetic concern; however, the undesirable aesthetic effects were more likely in naturally fluoridated areas. The York review found no association between fluoride in water and cancer, fracture of bones and other claims of health concerns; and found the water fluoridation effective even in wider presence of fluoride toothpastes (The NHS Centre for Reviews and Dissemination, 2000) [16,14] however, argued that the York review was "overoptimistic in assessment of evidence in favour of water fluoridation".

According to Peckham [11], Dean's investigation was to assess the ill effects of fluoride and demanded more studies on the preventive benefits. He stated that "Dean himself did not support studies initially due to concerns of toxicity"; however, the United States Public Health Services (USPHS) adopted the "optimal fluoride level" concept. Peckham [11] questioned the evidence base for the policy on fluoridation of water and emphasized that public health intervention and medical interventions differed in a sense that the former required a stronger evidence as it was for the persons who are "not diseased" or are not "seeking care". He further argued that artificial fluoridation schemes were a reflection of what was known as "Gold Effect" in literature; wherein like-minded people reinforced mutual ideas that got propagated. He also expressed concerns about the effectiveness in reduction of caries and dental health disparities, safety, cost effectiveness of artificial fluoridation and ethical issues. Artificial fluoridation is carried out with a substance hexafluoro silicic acid which is a phosphate byproduct and not the calcium fluoride which is a naturally present fluoride in water. Furthermore, he drew attention to the few critics' arguments that fluoride was a toxic chemical waste, a substance from nuclear and aluminum industries, and had been implicated in toxicity and health problems such as fluorosis, cancer, neurological conditions, etc. Also, fluoridation of water amounted to be an "enforced medication" [11]. A systematic review [18] has reported a lower IQ in individuals living in a high fluoride area

compared to that of individuals living in a low fluoride area; [mean difference –0.45 (95% confidence interval: –0.56, –0.35)]. Mansfield [19] reported that 25% of the population in the UK consumed excess fluoride than what was defined as the safe intake limits in the Committee of Medical Aspects of Food Policy (COMA). In fluoridated areas, two third of the population consumes excess fluoride. The authors investigated the data from National Diet and Nutritional Survey in the UK of the daily fluoride intake and urine samples to report the same. They offered conclusions such as: Level of fluoride exposure was higher than the earlier estimates in the UK and fluoridation of water meant further excess consumption. The adverse effects on health need to be thoroughly investigated prior to starting any fluoridation project. Fluoride concentration in urine should be checked in all routine urine tests [19].

The National Research Council of the USA reviewed of over 1000 studies of the effect of fluoride in water and reported ill effects on central nervous system at 1.8 ppm, bone fractures at less than 1.2 ppm, hypothyroidism at 1 ppp, osteosarcoma at 1 ppm and hypersensitivity at 0.25 ppm [20,9] reviewed reports of various health concerns related to water fluoridation such as dental and skeletal fluorosis, hip fractures, immunological, carconogenis, genotoxic, teratogenic, reprotoxic, nephrotoxic effects, goiter, effects on gastrointestinal system (non-ulcer dyspepsia), intelligence, etc. and found little evidence to support most of the implications. However, the author stated that indirect effects such as leaching of lead through pipes and aluminum from cooking vessels; and the effect of impurities in the added Na2SiF6 need to be evaluated [9].

The concept of optimal concentration (1 ppm) has been criticized by authors. Peckham [11] stated that there is no consistency in the optimal concentration of fluoride in water, the same being 0.7 ppm in Canada, 0.8 ppm in Ireland, and 0.5 ppm in Hong Kong. He further stated that the US government was considering reducing the same to 0.7. This level, however, is unsafe for infants as the dose is not dependent on their weight. He also reported that fluorosis of aesthetic concern was seen in 7 to 14% people and the prevalence of fluorosis was as high as 54% in some areas [11]. The risk of fluorosis has been attributed to the use of all fluorides and water fluoridation is no exception [12]. The authors reported that there were various difficulties in assessing the risk due to factors related to fluoride absorption because of individual variation in consumption, effect of diet, effect of air temperature, time lag between the consumption of fluoride and measurement, etc. Furthermore, the susceptibility of tissues to fluorides during formation (early years of life) and a possibility of excess consumption at young age (higher dose on the basis of weight) have important health implications related to water fluoridation in early life [12]. Recently, milk formulas have come under scanner in the United States after the American Dental Association recommended that that infant formula should not be prepared with fluoridated water [21] and it was also reported that the exposure to fluoride in not only the first year of life but also the next two years (2-4 years) is important for the risk of fluorosis [22]. Also, the exposure to fluoride occurs due to the “halo effect”, i.e. through the foods and drinks prepared from the use of fluoridated water, and that can be significant [12,15].

[23,14,11] questioned the effectiveness of water fluoridation in view of declining dental caries in the highly developed countries. Another study [23] stated that in view of the research indicating the post-eruptive effects of fluorides in preventing caries, low concentration topical fluoride exposures should be recommended. Moreover, the authors added that the benefits of water fluoridation declined since 1980s due to wide availability of fluoride containing toothpastes and oral care products. Another study [14] compared the caries reduction in the highly developed European countries with water fluoridation (Germany, Ireland, Portugal, Spain, and UK) and without (Austria, Denmark, Finland, Netherlands, Sweden, Greece and Italy) and reported a similar trend in decline of caries experience in both the populations. Peckham [11] also made a similar comparison between countries with fluoridated supplies between 40 and 70% (Australia, Ireland, New Zealand and USA) and countries with non-fluoridated supplies or fluoridated supplies less than 10% (Austria, Finland, Greece, Iceland, Italy, Japan, Portugal, Netherlands, Spain, Sweden and UK) and reported a similar decline. Burt [24] reported that two important determinants of dental caries were the socio-economic status and water fluoridation in the United States. He stressed the importance of water fluoridation considering it as the only possible way of reducing inequalities in the dental health across different socioeconomic strata [23-25,14] found poor evidence to state that fluoridation reduced dental health disparities, research [11,23] further stated that fluoridation did little to change the causes of dental caries such as the socioeconomic status, lifestyles and behaviors of people.

The caries reduction benefits of water fluoridation have been reported in more than 100 reports from 23 countries, with more than 60 studies presenting data for the primary teeth and more than 80 studies presenting data for the permanent teeth [12]. However, there have been possible errors due to variations in the study designs, inconsistent criteria for caries diagnosis, poor blinding of examiners, lack of randomization, comparison of geographic areas and clusters which may be dissimilar at baseline, publication bias owing to more reporting of positive research in the literature, etc. overestimating the results [12].

Effects of cessation of water fluoridation [23] reported that the caries experience remained static or continued to decline despite termination of water fluoridation after many years of implementation in a few populations: “Kupio and Jyvaskyla in Finland; Chemnitz and Plaven in Germany; Tiel and

Culemborg in Holland and La Salud in Cuba". However, it was reported [3] that in older studies, prevalence of caries was seen to increase to pre-fluoridation levels after cessation of fluoridation of water. A recent report by McLaren et al. [5] reported a reversal of trend, too.

Pine [13] summarized the advantages of water fluoridation such as low per capita costs especially in large communities, saving a great deal of treatment costs (fluoridation was estimated to cost $ 3.35 per carious surface saved), no requirement of additional manpower, benefitting the whole community, etc. However, it was also pointed out that the financial cost of dealing with the opposition to fluoridation can be high for the public health administrators [13]. The 'passive' nature of water fluoridation meaning it will be available to everyone when the scheme is implemented, may benefit those with a higher baseline risk (such as the deprived communities); however may meet stronger opposition in communities where the caries risk is low and unlikely to reduce further, and the risk of fluorosis outweighing the benefits of caries reduction [12,13].

Although some authors stated that there is no additional benefit from water fluoridation in countries with low caries levels and wide availability of fluoride dentifrices [23,11] others argue the necessity of it [26] opined that the battle against caries was yet to be won and pointed out to the area-specific differences in the caries experiences in the UK being as high as five-fold. The best caries level in the five-year olds found in Staffordshire was 0.6 dmf, whereas the worst in Blackburn was 3.2 [26]. The authors further argued the benefits of water fluoridation comparing the two cities Manchester and Birmingham, the former receiving non-fluoridated supply unlike the latter; stating that if supplies were fluoridated in Manchester, there would be 40,000 fewer carious teeth and 2600 fewer general anesthetics per year and 5500 caries-free children [26].

The ethical and legal arguments by opponents to the water fluoridation have been significant in the history of events. There has been no ruling against water fluoridation in the court of law in the Unites States; and in one of the longest court cases in the British history, the Strathclyde case, the judge found the evidence for the safety of water fluoridation convincing Pine [13] also stated that the opposition argument based on the health concerns although had little scientific basis, had a strong emotional appeal. The opposition was also based on the perception of freedom to choose and studies [12,14] also expressed the ethical concern regarding the autonomy of people and right to give or withdraw consent to the use of a medicinal product.

Another study [26] cited the Nuffield Council on Bioethics report in 2007 as the one that balanced individuals' autonomy on one hand and with the collective good on the other. Authors stated that the case for fluoridation became more robust when considered with ethical perspective. In support, they cited a dentist's argument whether "it is morally acceptable to allow children to suffer the pain and discomfort of decayed teeth and allow them the trauma of tooth extractions, sometimes under general anesthetics, when a simple way of adjusting the concentration of a naturally occurring element that goes a long way in alleviating these problems". Research [26] emphasized on the fact that even while considering "public opinion", one must remember that children do not have a voice.

Fluoridation of water has also been implicated in with the prospect of a "critical mass" in the environment which is harmful to plants and livestock [27].

Future of water fluoridation: Is water fluoridation still a good public health measure?

Dental caries still continues to be a major concern and an expensive disease to treat in the highly developed countries [28]. It is reported as the commonest childhood disease in the US; "five times more common than asthma" [29,30], dental caries could be increasing again due to the changes in global demographics, with immigrations to Western countries from Asian countries, and within Asian countries, from rural to urban areas. The author also mentioned other reasons such as changing eating patterns, use of bottled water rather than tap water containing fluoride [30]. A recent Australian paper supported fluoridation of water, stating that the odds ratios of caries in non-fluoridated area were 1.34 (95% confidence interval (95% CI 1.29, 1.39) and 1.24 (95% CI 1.21, 1.28) in the deciduous and permanent dentitions, respectively [15].

Despite opposition, controversies and interruptions in some programmes of water fluoridation; the recommendation on plugging off the water fluoridation as a strategy in caries prevention is unlikely. The alternatives to water fluoridations, such as the salt and milk fluoridation, although, offer consumers a choice and therefore less controversial, require promotion and are susceptible to varied consumption [3]. Nevertheless, another alternative to fluoride delivery, the fluoride toothpastes, continues to attract higher costs, is susceptible to behaviors of people, may not adequately benefit deprived communities with a higher caries experience and still possess some risk of fluorosis through ingestion [3,12].

Furthermore, recent articles have concluded that mild fluorosis that is usually seen with water fluoridation is not perceived as a serious aesthetic concern by people and has little impact on oral health related quality of life [31,32].

CONCLUSION

Fluoridation of water is the only practical whole population strategy that can also reduce the disease levels in the high-risk groups, too, and thus reduce dental health inequalities. It is also a cost-effective method; however, in the highly industrialized countries, one must consider the opportunity costs involving seeking people's opinion, legal issues,

promotion, etc. apart from the actual costs. Further research is needed to throw more light on the health concerns related to water fluoridation, and monitoring of fluoride level during routine urine testing could be valuable. Similarly, the perceptions on quality of life of mild fluorosis and dental caries among people need to be investigated. With growing health concerns and reduced relative effectiveness, water fluoridation schemes need to be planned well by the public health administrators based on targeting areas with high deprivation and caries levels. Decision making on initiating, maintaining or terminating water fluoridation schemes must also take into consideration trends in caries experience, availability of and acceptance to fluoride containing oral care products (mainly the toothpastes), dietary habits of people in the communities, feasibility of an alternative (salt or milk fluoridation), and other factors such as use of bottled water for drinking by people, etc.

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