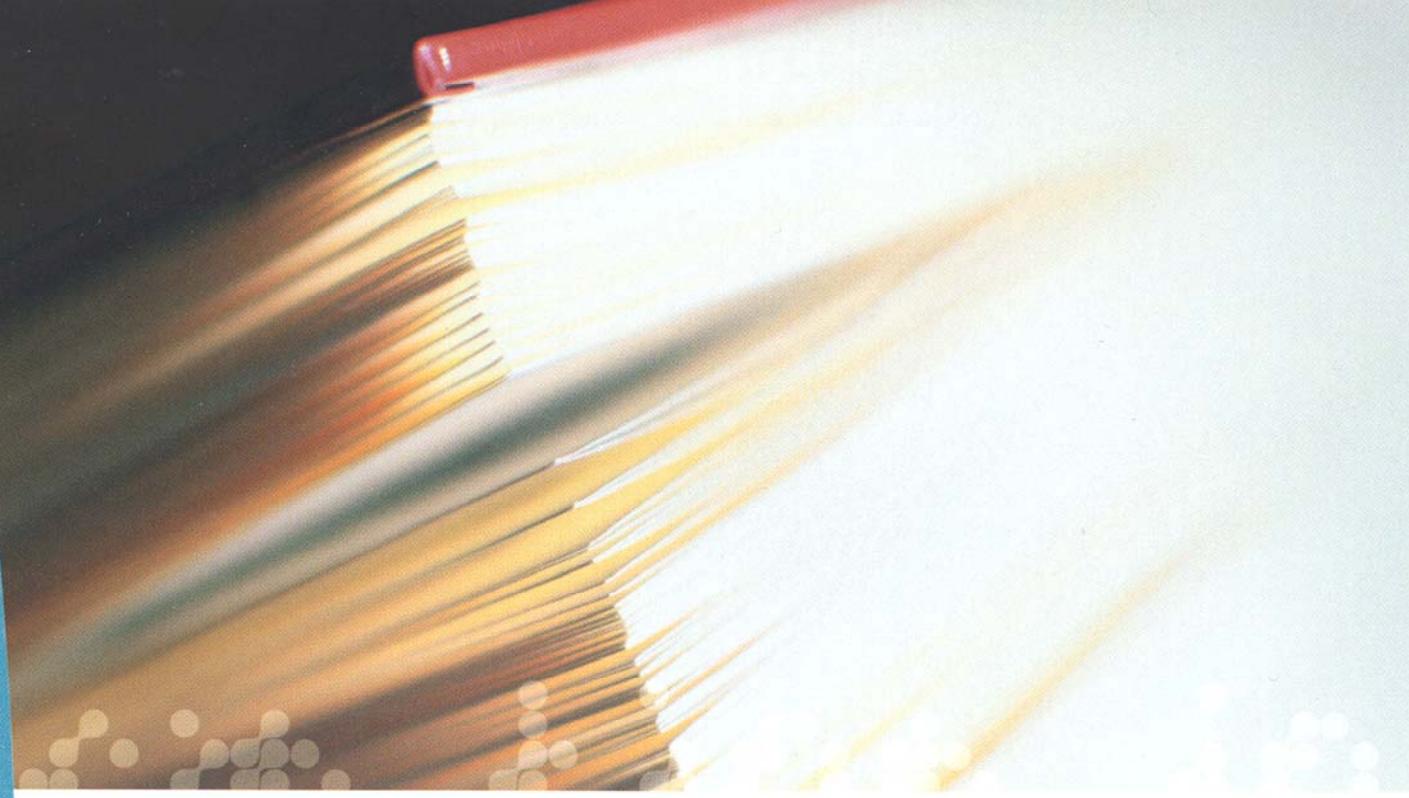

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WATER FLUORIDATION : AN ANALYSIS OF THE HEALTH BENEFITS AND RISKS

SCIENTIFIC ADVISORY

INSTITUT NATIONAL DE SANTÉ PUBLIQUE DU QUÉBEC

Québec

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DÉVELOPPEMENT DES INDIVIDUS ET DES COMMUNAUTÉS

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FOREWORD

Water fluoridation is a public health measure that has been used for approximately sixty years to reduce the incidence tooth decay in the general population. This preventive measure is recognized by the scientific community as being safe, economical and effective. Moreover, it reaches all segments of the population, particularly the poor, for whom other preventive measures may be inaccessible. Despite concerns over the environmental impact of fluoridation, studies conducted to date have not demonstrated any harmful effects on the environment. Still, the debate concerning the benefits and the negative effects of fluoridation is ongoing, especially because the public regularly expresses concern over the addition of fluoride to water and the potential health risks of this practice.

Many international health organizations, including the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) in the United States, recommend water fluoridation as a means of preventing tooth decay. According to the CDC, water fluoridation is one of the 10 most important public health achievements of the 20th century, alongside vaccination, infectious disease control, the decline in mortality resulting from cardiovascular disease, and tobacco control. The WHO has identified fluoride as one of 14 minerals considered essential to good health.

The Quebec Public Health Act (PHA) calls for the inclusion of measures to promote water fluoridation in the Quebec Public Health Program 2003-2012 (PNSP). The 2003-2012 PNSP promotes optimal use of fluoridation to prevent tooth decay. The recent provincial oral health action plan 2005-2012 (PASDP*)* sets out actions to ensure that 50 % of the Quebec population will have access to drinking water containing an optimal concentration of fluoride by 2012. It should be noted that, in 2006, only 7 % of the Quebec population had access to optimally adjusted water fluoridation.

Section 57 of the Public Health Act (R.S.Q., c S-2.2) passed into law by the Quebec government in 2004 provides that the fluoride concentration required to prevent tooth decay—while also minimizing the risk of dental fluorosis—be set at 0.7 milligrams per litre of water (mg/L). This concentration, to which all water treatment plants that perform fluoridation must comply, had formerly been set at 1.2 mg/L. Lowering the allowable concentration was aimed at reducing total intake of fluorides from all sources, while maintaining the beneficial effects of fluoridation as a means of preventing tooth decay.

The Institut national de santé publique du Québec (INSPQ - Quebec public health institute) agreed to produce this document on water fluoridation at the request of the ministère de la Santé et des Services sociaux (MSSS – Quebec department of health and social services). It represents a synthesis of current knowledge on the beneficial effects and potential health hazards of the fluoride levels set under the Quebec government's water fluoridation regulations.

This synthesis will allow to determine whether the position of the MSSS (Quebec department of health and social services) with respect to the safety and efficacy of community water fluoridation needs to be reviewed or should remain unchanged.

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LIST OF ABBREVIATIONS

ANSI: American National Standards Institute

AWWA: American Water Works Association

CDC: Centers for Disease Control

CHSLD: Centre d'hébergement et de soins de longue durée (Long-term care facilities)

DMFT: Decayed, missing, or filled teeth in permanent dentition

EPA: Environmental Protection Agency

INSPQ: Institut national de santé publique du Québec (Quebec public health institute)

LSPQ: Laboratoire de santé publique du Québec (Quebec public health laboratory)

MAC: Maximum Allowable Concentration

MCL: Maximum Concentration Level

MSSS: Ministère de la Santé et des Services sociaux (Quebec department of health and social services)

MDDEP: Ministère du Développement Durable, de l'Environnement et des Parcs (Quebec department of environment)

NCI: National Cancer Institute

NRC: National Research Council

NSF: National Sanitation Foundation

PASDP: Plan d'action de santé dentaire publique 2005-2012

PNSP Programme national de santé publique 2003-2012 (Quebec Public Health Program 2003-2012)

RAMQ: Régie de l'assurance maladie du Québec (Quebec health insurance board)

WHO: World Health Organization

INTRODUCTION

The fluoride ion is the ionic form of the element fluorine, which is found in abundance in nature, primarily in water and soil. Given its extreme reactivity, fluorine is never found in nature in its elemental form, only in the form of compounds known as fluorides. Sea water contains 1.2 to 1.5 mg/L of fluoride in its ionic form, while fresh water found throughout Canada contains 0.01 to 11 mg/L (1, 2). Although natural levels greater than 4 mg/L are extremely rare in Quebec, levels as high as 28 mg/L have been measured in a well in Gaspé (3). Many natural products, such as tea and fish, contain significant quantities of fluorides (1).

1. EFFECTS OF FLUORIDES ON TEETH

1.1. MODES OF ACTION OF FLUORIDE IN CONTROLLING AND PREVENTING TOOTH DECAY

Tooth decay is an infectious disease in which bacterial acids cause the dimineralization and dissolution of the hard tissue of teeth. Fluoride acts in a variety of ways to prevent and arrest tooth decay. When the fluoride ion is present in dental plaque and saliva, it prevents the demineralization of enamel and promotes remineralization. The action of cariogenic bacteria produces a drop in pH, bringing about the dissolution of hydroxyapatite crystals, the most important component of enamel. This drop in pH causes the fluoride ion found in plaque to be released. Because the fluoride ion is absorbed into the demineralized enamel, it renders the enamel more resistant to dissolution. Fluoride is absorbed more easily by demineralized enamel than by healthy enamel. It displaces the hydroxyl ion in hydroxyapatite crystals to form fluoroapatite crystals that are more resistant to the acids that promote tooth decay (4). When present in high amounts, the fluoride in dental plaque inhibits bacterial activity, thereby reducing the production of the acid and polysaccharides that constitute the matrix of dental plaque (4).

Current scientific literature indicates that the action of fluoride is primarily topical, that is it acts after teeth have erupted by increasing the concentration of fluoride in saliva and plaque (4). However, a number of recent studies indicate that fluoride also plays a beneficial systemic role (5-10). The pre-eruptive systemic effect is thought to play an important role in preventing decay in the pits and fissures of teeth, while a combination of pre-eruptive and post-eruptive (topical) effects contributes to optimal cavity prevention on smooth surfaces (5,6,7). The systemic action of fluoride occurs in two ways. First, it plays a predominant role when fluoride exposure occurs during the period of tooth crown formation (7). Fluoride becomes part of the tooth structure during the pre-eruptive phase, as the tooth is forming, making the tooth more cavity-resistant. Second, the systemic effect is linked to additional topical exposure of the teeth already present in the mouth: once ingested, the fluoride ion is continually excreted in saliva, with the salivary glands acting as fluoride reservoirs (8). According to one study, child populations at high risk of dental decay would derive the greatest benefit from the pre-eruptive effect of fluoride (9). Moreover, individuals exposed to fluoridation from birth derive maximum benefit from both its systemic and topical effects (10).

Maximum caries reduction results from the combined mechanisms of systemic exposure (before tooth eruption) and topical exposure (after tooth eruption). Accordingly, water fluoridation is believed to optimize prevention through this dual action (5-10).

1.2. BENEFICIAL EFFECTS OF WATER FLUORIDATION ON DENTAL HEALTH

In the early 1930s, researchers began to notice that people who drank naturally fluoridated water had very few cavities. This low prevalence of tooth decay was also associated with teeth that were mottled in appearance, a condition we now refer to as dental fluorosis. From this observation came the idea of adding fluoride to water systems in which fluoride concentrations were not sufficient to protect teeth, while also seeking to minimize the risk of dental fluorosis. Since then, numerous studies and systematic reviews of the scientific literature have amply demonstrated the beneficial effects of water fluoridation (4, 8, 11-14). These effects can be obtained, while also minimizing the risk of mild and very mild fluorosis in young children, by maintaining fluoride concentrations between 0.7 and 1.2 mg/L (15).

Health Canada has set the maximum allowable concentration (MAC) for fluoride in drinking water at 1.5 mg/L, a concentration it views as providing maximum benefits for dental health, while also avoiding unnecessary risks related to fluorosis. This standard has also been adopted by the Quebec government. Health Canada recommends that communities wishing to add fluoride to their drinking water should aim for fluoride concentrations between 0.8 and 1.0 mg/L (16).

Despite the diminishing prevalence of dental caries among children in Quebec and elsewhere, the WHO still views water fluoridation as the safest, most economical and most effective means of preventing and controlling tooth decay (17). In their most recent position on this subject, the United States Centers for Disease Control and Prevention (CDC) also maintains its support for water fluoridation, arguing that the practice is both safe and equitable, since all population groups benefit from it (4). In fact, the CDC ranks water fluoridation as one of the 10 great public health successes of the 20th century (18). According to the WHO and the CDC, the populations that are the most underprivileged and the hardest to reach with conventional preventive services are also the populations most likely to benefit from fluoridation. In this sense, fluoridation can be seen as a public health measure that reduces social inequalities in dental health. Hundreds of other health organizations in the United States and around the world also support drinking water fluoridation (Appendix 1).

In a recent report (2005), the WHO lists fluoride as one of the 14 minerals considered essential to good health (19). According to the The Linus Pauling Institute for Micronutrient Research, if one considers the prevention of chronic disease (dental caries) an important criterion in determining essentiality, then fluoride might well be considered an essential trace element (20, 21). In 1998, the Institute of Medicine of the National Academies of Sciences also declared that fluoride was an important nutrient, owing to its beneficial health effects (22).

Comparisons of communities where water is fluoridated and communities where water remains unfluoridated show a reduced prevalence of dental caries in the range of 18-40 % when fluoridation is used (4). A recent study established the rate of caries reduction at 25 % (23). It is postulated that this estimate is more conservative than those reported in the past because the general population now enjoys the benefits of fluoride from other sources, such as fluoride-enriched toothpaste and vitamin supplements.

Four meta-analyses published since 1999 have shown that stopping fluoridation in a community generally results in an increased prevalence of dental caries (4, 8, 12, 13).

Between 1977 and 1986, a survey of the oral health of children aged 6-7 was conducted in two Quebec municipalities: Windsor, where the water is fluoridated, and Richmond, a neighbouring and comparable community where the water is not fluoridated. The study found that between 1977 and 1986, the DMFT (decayed, missing and filled teeth) index declined by 61.8 % in Windsor and 34.4 % in Richmond, relative to 1977 figures. Significant differences in molar morphology were also observed between the two groups: children residing in the municipality of Windsor (fluoridated water) had shallower dental fissures, making their teeth less vulnerable to caries than the children in Richmond (24).

Data collected on children enrolled in public schools in Dorval between 2003 and 2006 indicate that the percentage of kindergarten children at high risk of developing dental caries doubled in the two-year period after water fluoridation was halted in 2003, rising from 8 % to 17 %, which represents a statistically significant difference (25). Although the data present certain methodological limitations, they were corroborated in independent modelling studies conducted by the INSPQ (25).

It has been well established that the benefits of fluoridation are greater for people who live in conditions of material deprivation (26-29). Furthermore, while the majority of studies examined the effect of fluoridation on the dental health of children, meta-analyses have established that adults and seniors also benefit from this measure (4, 8, 12, 30). Caries reductions of approximately 15-35 % have been observed in adults and seniors who reside in communities with fluoridated water (8). Seniors are especially vulnerable to tooth decay, particularly root decay. This is linked to a variety of factors, including gum recession and decreased saliva production associated with the use of certain drugs prescribed to treat the many chronic illnesses that affect the elderly (4). Another factor is that many seniors in Quebec are poor and therefore have limited access to dental care. A recent study conducted in three Quebec regions (Montreal, Montérégie and Quebec City) revealed the deplorable oral health of seniors aged 65 and older who reside in the province's long-term care facilities, the *Centres d'hébergement et de soins de longue durée* (CHSLDs) or who receive home care. Among dentulous long term care facilities residents, 49 % had dental caries (31). In Montérégie, this was true of 61 % of long term care facilities residents (32). The authors of this study concluded that the oral health of seniors in Quebec's long term care facilities residents has not really improved since 1980 (31, 32). As the general population ages, this increase in the oral health problems of seniors could be mitigated considerably by fluoridation. In the United States, water fluoridation is viewed as a cornerstone of any public-health program (33). It constitutes one of three public-health measures recognized as being effective against dental caries, the other two being dental sealants (14) and professionally applied topical fluorides (34). Although commonly used in Quebec, the latter two preventive measures act on individuals rather than populations. They require considerable financial and human resources and are necessarily limited to the groups most vulnerable to tooth decay. Moreover, despite the considerable effort these individual approaches require, their impact is limited for a variety of reasons:

1. Identification of persons at high risk of dental caries is difficult, particularly before signs of clinical disease appear. Furthermore, while a past history of caries remains the best predictor of future caries, its predictive value is nonetheless fairly limited.

2. Even when at-risk groups are identified, it is often difficult to reach them to provide the necessary preventive services.

3. The preventive effect of professionally applied fluoride is temporary, unlike the permanent benefits of water fluoridation.

4. In Quebec's dental public health program, professional measures to prevent caries are limited to children within a certain age range, usually kindergarten to grade two.

5. Since the majority of Quebec children aged 0-5 years who are considered to be at risk have not benefited from fluoridation since birth, tooth decay is often present by the time they reach kindergarten. Providing individual preventive care then requires considerable human and financial resources.

6. Although relatively expensive, sealants are only effective at preventing cavities on the occlusal surfaces of molars. They do not protect the smooth surfaces of teeth. Fluoridation, on the other hand, protects occlusal surfaces through its pre-eruptive effect and smooth surfaces through its post-eruptive effect. The combined action of sealants and water fluoridation therefore potentiates the protective effect of fluoride.

1.3. PROFILE OF THE DENTAL HEALTH OF QUEBEC CHILDREN

According to the results of the 1998-1999 study on the oral health of Quebec students aged 5-6 and 7-8, Quebec kindergarten children have 40 % more caries than their counterparts in Ontario and the United States (35). The same study showed that tooth decay affects 42 % of kindergarten children and 56 % of children in grade two. What is more, the results of an exploratory study carried out in three underprivileged communities in the Montreal area show that 50-70 % of children in junior kindergarten had dental caries (36).

Another study indicates that 34.8 % of children aged 11-12 have, on average, 4.4 DMFT. This means that more than a third of Quebec children fail to meet the goal of less than 3 DMFT set by the WHO in 1979 as a population-wide average (37).

According to the authors of the 1998-1999 study, the observed decline in temporary dentition caries is coming to an end and the decline observed with respect to permanent dentition caries is clearly slowing (31). Moreover, the percentage of kindergarten children province-wide who are at risk for dental caries has not diminished in recent years, despite the implementation of a preventive dental public health program (38).

1.4. CONSEQUENCES OF NON-FLUORIDATION FOR DENTAL HEALTH

As stated earlier, water fluoridation is recognized as the most effective means of reducing dental caries, particularly among the most underprivileged segments of society. In Quebec, the poorest citizens have rates of dental caries 2.5 to 3 times higher than the more affluent socio-economic strata of society; the poor also have less access to dental care than other groups (35). The same phenomenon has been observed among new immigrants, Aboriginals and remote communities (39). The lack of water fluoridation or the cessation of this practice in a community is clearly detrimental to the more vulnerable members of the population.

The consequences of tooth decay are far from benign: they can affect mastication, nutrition, appearance, general well-being (33), economic productivity and quality of life (40, 41). A person's overall health is therefore affected (33). Several authors have demonstrated that people who have dental problems experience more rejection and stigmatization than others, along with feelings of embarrassment and low self-esteem (33, 40, 41).

In addition to the physical and psychological suffering associated with dental caries, other aspects to consider are the potential complications linked to this condition, such as the administration of general anesthesia to young children and school absenteeism. Moreover, the enamel and dentine destruction caused by dental caries is irreversible. Even after repairs are made, damaged teeth will need to undergo recurring and increasingly invasive treatments throughout life. When left untreated, dental caries can accelerate the progression of periodontal disease, which is now taken far more seriously in the scientific literature, given the association of this condition with numerous harmful health effects, including heart disease and delayed intra-uterine growth (42, 43). In the frail elderly, untreated caries can have serious consequences on general health and can even be life-threatening (44). Similarly, persons who suffer from certain serious diseases that leave them in a weakened state are at particular risk when required to undergo dental surgery.

These considerations led the Montreal public health department (DSP de Montréal) to declare that failure to provide the primary prevention afforded by drinking water fluoridation to populations that are vulnerable to dental caries represents negligence towards the health of the population on the part of decision-makers (45).

1.5. DENTAL FLUOROSIS

Excessive, chronic ingestion of the fluoride ion during tooth formation can lead to tooth discoloration, which in most cases takes the form of slight, whitish spots that are barely visible and tend to fade over time. This change in the appearance of teeth is known as dental fluorosis. Other etiological factors, such as exposure to amoxicillin at an early age, can have a similar effect on teeth appearance (46). Fluoride-related fluorosis usually appears in children between birth and age 3, most commonly on the permanent central incisors (47), which are the most important teeth from an esthetic standpoint. With the exception of the third molars, enamel formation on permanent teeth starts around birth and is complete by about age 5. Later, dental enamel is completely mineralized and the risk of developing fluorosis disappears, even when fluoride is ingested in excessive amounts (48).

Dental fluorosis in its very mild, mild or moderate form, is not considered to be a toxic effect (49). In fact, numerous studies have shown that teeth that present such signs of fluorosis are more cavity-resistant (10). Mild or very mild fluororis is often imperceptible to the untrained eye, but moderate fluorosis, caused by the ingestion of large quantities of fluoride during tooth formation, does affect tooth appearance (49). Ingestion of very large quantities of fluoride during tooth formation can lead to severe fluorosis and enamel erosion, making teeth more vulnerable to decay. This undesirable effect is generally associated with water fluoride concentrations in excess of 4 mg/L (49). However, natural fluoride concentrations very seldom reach this level in Quebec. When they do, they are well above the concentration of 0.7 mg/L set under Quebec's water fluoridation regulations.

It is estimated that the mild effects of fluorosis begin to appear when children ingest between 0.05 and 0.07 mg/kg/day of fluoride from all sources. According to Heller, a fluoride level of 0.7 mg/L of drinking water is sufficient to provide dental health benefits and prevent dental fluorosis (50). This seems to be a conservative estimate and should be interpreted with care, since it was established in an American setting some years ago when children's use of fluoride supplements and toothpaste was far more widespread than it is among Quebec children today. The use and dosage of such products for young children have decreased considerably over the past 20 years, based on new recommendations from health organizations. Since early childhood fluoride intake from other sources appears to have diminished in Quebec over time, further research is needed to determine whether the fluoride concentrations allowed under current standards are sufficient to ensure optimal caries reduction.

Dental fluorosis is not considered a public-health problem in Quebec. Based on the results of the 1998-1999 study on the oral health of Quebec school children aged 5-6 and 7-8, fluorosis causing unacceptable esthetic effects (moderate or severe fluorosis) is extremely rare in Quebec (35). Of 5,079 grade-two children examined, only 1 % presented signs of mild fluorosis, and only a single subject showed signs of moderate fluorosis. In the latter case, the fluorosis was not linked to drinking water fluoridation but to ingestion of large quantities of fluoride toothpaste. No children presented signs of severe fluorosis. It is important to note, however, that this sample was primarily composed of children who did not have access to fluoridated water. On the other hand, at the time the study was conducted, use of fluoride supplements was more widespread than it is today and the amount of fluoride toothpaste used by young children was less strictly controlled.

In Quebec, children's intake of fluoride from all sources has reportedly decreased in recent years, particularly in municipalities where water is artificially fluoridated. Since 2004, all drinking water treatment plants in Quebec that practice fluoridation are required to maintain a fluoride concentration of 0.7 mg/L (51) which had formerly been set at 1,2 mg/L. Moreover, the recommendations issued by health organizations concerning children's use of fluoride-enriched supplements and toothpaste are far more restrictive than they once were. Therefore, it is unlikely that children who reside in areas where the fluoride concentration in drinking water has been adjusted to 0.7 mg/L will in future experience increased rates of fluorosis—aside from the most benign form of this condition.

However, studies have shown that there is an inevitable overlap between the level considered beneficial and the level which induces mild dental fluorosis in the population. From a public health standpoint, a low prevalence of mild dental fluorosis should not be seen as an undesirable effect since it constitutes a sign of increased protection against dental caries. Tooth decay associated with inadequate fluoride intake constitutes a far more serious health threat than mild dental fluorosis.

In 1994, a review of five independent studies demonstrated that only 13 % of all dental fluorosis is attributable to water fluoridation (52). This percentage therefore represents the proportion of dental fluorosis that would be avoided if fluoridation were stopped completely. In other words, most cases of dental fluorosis are attributable to other risk factors, most notably over-consumption of fluoride-enriched dental hygiene products by young children (52).

2. SYSTEMIC EFFECTS OF FLUORIDES ON HEALTH

2.1. GENERAL HEALTH EFFECTS

A number of organizations around the world have examined the effects of fluoride on human health. The reviews of the US Public Health Service (1991) and the National Research Council (NRC, 1993), which are frequently cited in the literature, report no toxic health effects associated with fluoride concentrations recommended to prevent tooth decay (53, 54). Two other systematic reviews of the scientific literature, one published in Australia in 1999, the other in the United Kingdom in 2000, came to the same conclusions (12, 13). More recently, in March 2006, the NRC published a toxicology report originating from a regulatory process of the US Environmental Protection Agency (EPA, which is required to review its standards periodically (49). The purpose of this report was to analyse the health effects of the maximum concentrations prescribed under EPA standards, namely the Maximum Concentration Level (MCL) of 4 mg/L and the Secondary MCL of 2 mg/L. These studies were carried out to re-evaluate American protection standards, not to establish a standard for the prevention of dental caries. These American standards are far higher than the Quebec standard of 0.7 mg/L that is deemed sufficient to prevent dental caries. The conclusions of the NRC should therefore be interpreted with caution.

2.2. EFFECTS ON ORGANIC SYSTEMS

According to the recent NRC report (2006), there is no evidence to suggest that fluoride in water in concentrations ranging between 2 and 4 mg/L can cause reproductive or developmental health effects. Nor does NRC report any effects on immune, gastro-intestinal, renal, hepatic, neurological or endocrine systems (49). However, the report does indicate that certain population sub-groups, such as persons suffering from kidney failure, may theoretically be more vulnerable, since they accumulate more fluoride in their bodies. The NRC has therefore recommended that certain research hypotheses be explored, particularly with respect to the neurological and endocrine systems.

Since the NRC found no undesirable organic health effects associated with chronic exposure to 2-4 mg/L of fluoride in the general population, it appears logical that the same conclusions apply when a population is exposed to a far lower level, such as that recommended under the Quebec standard, namely 0.7 mg/L.

2.3. SKELETAL FLUOROSIS

According to the scientific literature, skeletal fluorosis is extremely rare in North America (49). This condition is characterized by increased bone brittleness and a greater risk of fractures. According to a modelling study cited in the recent NRC report, skeletal fluorosis can occur when exposure to fluoride in drinking water exceeds 4 mg/L over a lifetime (49). However, the same report states that the studies currently available provide no evidence that long-term exposure to concentrations as low as 4 mg per litre of water carries a risk of skeletal fluorosis. Consequently, it is highly unlikely that the concentration of 0.7 mg/L recommended in Quebec would be associated with this condition. Nonetheless, some poorly documented

research hypotheses such as the link between renal insufficiency and bone fluoride retention are of interest and merit further investigation.

2.4. BONE FRACTURES

A systematic review of the recent literature uncovered no association between hip fractures and water fluoridation (12). On the contrary, a report by the Surgeon General published in the United States in 2004 states that fluoride is a nutrient that is potentially beneficial for bones (55). On the other hand, the NRC report concludes that daily lifetime exposure to concentrations equivalent to 4 mg/L was associated with an increased—albeit still weak—risk of fracture, when compared with a concentration of 1.0 mg/L. However, the NRC report also cites a study which shows that persons exposed to concentrations in the area of 1.0 mg/L present fewer bone fractures than any other group observed, even those exposed to concentrations below 0.3 mg/L (56). While not definitive, this observation suggests that a concentration of 0.7 mg/L may help prevent bone fractures. New studies are needed to elucidate this link.

2.5. OSTEOSARCOMA

A potential link between fluoride and cancer—osteosarcoma in particular—has been alleged by certain researchers. Since fluoride is deposited in the bones during bone formation, some have hypothesized that this phenomenon may induce osteosarcoma in growing children.

A number of expert committees have examined the link between fluoride and cancer. In 1991, the National Cancer Institute (NCI) conducted an exhaustive review of the US tumour registries and found no cancer risk attributable to fluoride in humans (57).

In 1993, the NRC presented a review of some fifty epidemiological studies on the relationship between drinking water fluoridation and cancer, including osteosarcoma. The NRC concluded that there was no proven link between cancer and the natural or artificial presence of fluoride in water (54).

Two other expert committees in the United Kingdom and Australia examined in considerable depth the link between fluoridation and cancer, including osteosarcoma. According to the reports of these committees, the current scientific knowledge on this subject does not establish a link between water fluoridation and cancer of any kind (12, 13).

In its 2006 report, the NRC examined research findings published since its last review in 1993 (49), including those from a number of epidemiological case-control studies on the link between fluoride and osteosarcoma. Case-control studies are more appropriate for investigating associations with rare diseases like osteosarcoma. According to the NRC report, the results of these studies are contradictory: some suggest that there is a link between fluoride and osteosarcoma, while others show no such link. Some studies even indicate that fluoride may have a protective effect against osteosarcoma. The report concludes that the studies published to date all present methodological weaknesses and offer no definitive conclusions.

A recent study from Harvard University has drawn considerable attention (58). This was a case-control study of 103 cases of osteosarcoma in persons under the age of 20, drawn from 11 different American hospitals. The results suggest that there is an association between fluoride levels in water and osteosarcoma in young boys. However, the author recommends against drawing hasty conclusions from this study since a number of confounding factors had not been taken into account and that further investigation is needed.

The definitive results of a subsequent Harvard study will be published in the near future (69). This study examined osteosarcoma cases from the same hospitals as in the previous study, but identified between 1993 and 2000. The preliminary results of this study, which used diagnostic and exposure measurement methods similar to those used in the previous study, have not demonstrated any association between exposure to fluoride and osteosarcoma. In addition, the investigators also examined subjects' bones for fluoride content and did not find any link between the rates of fluoride present and an increased risk of developing osteosarcoma. It should be noted that analysis of bone fluoride content to verify the biological plausibility of a link between fluoride accumulation in the body and osteosarcoma incidence was strongly recommended in the NRC report published in 2006 (49).

In summary, most of the studies published to date on the subject of fluoridated water consumption do not support the hypothesis of a link between fluoride exposure and an increased risk of developing osteosarcoma. However, given the methodological limitations of these studies, other well-controlled studies should be carried out in order to determine if such a link actually exists.

2.6. LEAD EXPOSURE AND FLUORIDATION

In the United States lead pipes were used in water supply lines until the 1930s and lead soldering was permitted until 1986. According to two studies published in 1999 and 2000, fluorosilicic acid and sodium fluorosilicate used in water fluoridation may accelerate lead leaching in these pipes and thus increase lead accumulation in children (60, 61). Investigators at the US EPA conducted an exhaustive review of these two studies and concluded that the underlying scientific rationale was not valid (62). An epidemiological study published in January 2006 arrived at similar conclusions. The latter study tested the hypothesis that children who reside in older buildings where water is naturally or artificially fluoridated have greater exposure to lead than children living in newer buildings where the use of lead pipes and lead soldering is less widespread (63). The sample in this study was composed of 9,477 children. Although an association was observed between the use of fluorosilicic acid and the blood lead levels of children living in buildings constructed before 1946, an inverse relationship was observed between these two variables in the case of housing of medium age. In fact, the blood lead levels of children living in buildings constructed before 1946 were lower that those who lived in more recent buildings, contrary to expectations. The authors concluded that their observations did not support the hypothesis of a link between water fluoridation and higher blood lead levels in children, although this possibility cannot be entirely ruled out. The authors added that their results do not justify any modification of drinking water fluoridation practices.

More recently, in June 2006, an investigation using an experimental laboratory design that simulated field conditions uncovered no evidence that the products used in fluoridation cause lead leaching in water lines (64).

It is important to note that lead leaching in water lines depends on water acidity and other factors such as temperature or the presence of oxygen, hydrogen sulfides, or certain bacteria, and not on the presence of the fluoride ion. When water is already naturally acid, a slight increase in acidity may be noted, particularly when alum, chlorine or fluorosilicic acid are added (65). In these cases, water treatment plants periodically take measures to neutralize the acid level, in accordance with section 17 of Quebec's water quality regulations (66).

3. ENVIRONMENTAL IMPACT OF WATER FLUORIDATION

The effects of water fluoridation on the environment have been analysed in a number of studies, all of which come to the conclusion that fluoridation poses no risk for plant or animal life (67-70). Two studies looked specifically at the potential effects of water fluoridation in Montreal on the aquatic plant and animal life of the St. Lawrence River. Both came to the conclusion that no harmful effects could be expected (64, 65). Fluoride is abundantly present in nature and the quantity being added is both imperceptible and innocuous, according to these studies.

Quebec's department of environment, the Ministère du Développement Durable, de l'Environnement et des Parcs (MDDEP), has also reviewed the literature on this subject and has arrived at similar conclusions (71).

4. CURRENT STATE OF WATER FLUORIDATION IN QUEBEC

4.1. ACCESS TO FLUORIDATED WATER IN QUEBEC

In Quebec, only a dozen water treatment plants add fluoride to drinking water to achieve the concentration of 0.7 mg/L required by law (72). A larger number of systems distribute water that is naturally fluoridated at concentrations deemed to be beneficial to dental health (0.7 to 1.2 mg/L), but the vast majority of water systems in Quebec have lower water fluoride concentrations that do not offer such benefits. For example, the fluoride concentration in Montreal's drinking water is less than 0.2 mg/L.

In 2004, 66 % of the American population (73) and 75 % of the Ontario population (74) had access to fluoridated drinking water. In Quebec, however, only 7 % of the population currently has access to fluoridated water (75).

4.2. WATER FLUORIDATION CHEMICALS

4.2.1. Classification of chemicals used in Quebec

Three types of chemicals are used in water fluoridation. Their selection is based on several factors, including the flow rate of water treatment plants, the technical training of personnel, cost, individual preferences, water pH, etc. The three chemicals used are sodium fluoride, sodium fluorosilicate, and fluorosilicic (or hexafluorosilicic) acid. These chemicals are not derived from the aluminum industry, but rather from the phosphate industry.

4.2.2. Quality criteria for water fluoridation chemicals

Quality control of chemicals used for drinking water fluoridation in Quebec is currently overseen by the MSSS (Quebec department of health and social services), through the LSPQ (Quebec public health laboratory). This monitoring provides a means of verifying the analytical performance of municipalities, the fluoride content of water distribution systems, and the quality of water fluoridation chemicals (76).

In Quebec, the chemicals used to treat drinking water are governed by the quality standards of the American Water Works Association (AWWA), the American National Standards Institute (ANSI), and the National Sanitation Foundation (NSF).

Before awarding contracts to suppliers, the MSSS (Quebec department of health and social service), ensures that the chemicals used in water fluoridation meet the following standards: ANSI/AWWA B701 for sodium fluoride, ANSI/AWWA B702 for sodium fluorosilicate, and ANSI/AWWA B703 for fluorosilicic acid (77). For quality control purposes, the MSSS also maintains standards and guidelines on drinking water fluoridation in Quebec; these require municipalities to submit samples of every shipment of chemicals they receive to the LSPQ, for compliance testing purposes. The standards in force at the LSPQ are those cited above; and also include fluoride concentration, granulometry, insoluble matter, moisture and heavy metals, depending on the chemicals submitted.

Chemicals must also meet the very strict ANSI/NSF Standard 60, established by the National Sanitation Foundation (NSF) in conjunction with a consortium of organizations, including AWWA and ANSI (77). This standard applies to all chemicals added to drinking water by treatment plants; it also establishes maximum allowable concentrations (MAC) for 11 metals that are regulated by the Environmental Protection Agency (EPA) in the United States, including arsenic, chromium and lead. For a product to be certified by the NSF under ANSI/NSF Standard 60, the concentration of any contaminant, once the product has been diluted in water, must not exceed one tenth of the maximum allowable concentration (MAC) permitted by Health Canada or the maximum concentration level (MCL) allowed by the American EPA. For example the MAC set by Health Canada for arsenic is ten parts per billion or ten micrograms per litre (10 μg/L), which means that the concentration of arsenic, once the product has been diluted in water, must not exceed 1.0 μg/L, which is a minute concentration (78). In order to meet the requirements of ANSI/NSF Standard 60, testing must be carried out in a recognized laboratory, such as the Underwriters Laboratories (77).

4.2.3. Purity of water fluoridation chemicals

Although some have alleged that the chemicals used in fluoridation are contaminated with arsenic, lead, mercury, cadmium, etc., this assertion is inaccurate. The NSF conducted contaminant concentration tests on all the water fluoridation chemicals that it registered and certified between 2000 and 2006. Tests were carried out on 245 product samples diluted in water at a concentration corresponding to 1.2 mg/L of fluoride, the current standard for the prevention of tooth decay. The test results systematically demonstrated that, at this dilution, contaminant concentrations were well below the recommended 10 % of the MAC (79, 80).

Arsenic was sometimes present, but in extremely low concentrations, whereas other metals were generally not detected. When arsenic was present, the average concentration corresponded to a barely detectable amount that ranged between 0.29 μg/L and 0.6 μg/L, the highest level recorded. These concentrations never exceeded the 10 % of MAC standard, the rate currently allowed under ANSI/INSF Standard 60, corresponding to 1.0 μg of arsenic per litre (80). In Quebec, the optimum concentration of fluoride allowed under drinking water regulations is only 0.7 mg/L, not 1.2 mg/L. Therefore, at a dilution corresponding to 0.7 mg/L, arsenic concentrations would be proportionally lower than those recorded by the NSF. Thus, the highest arsenic concentration recorded, namely 0.6 μg/L, would in fact correspond to 0.35 μg/L in Quebec's fluoridated water, which is less than one tenth of the maximum concentration allowed in Canada (1.0 μg/L).

In 1998, the NSF began testing water fluoridation chemicals for the presence of radioactive contaminants (alpha and beta particle emitters) using the EPA 900.0 method outlined in Appendix B of ANSI/NSF Standard 60. No alpha or beta particles were detected in these tests, which were carried out between 1998 and 2006 (80).

It is believed that the most probable source of contaminants in fluoridation chemicals is linked to transportation and not manufacturing (e.g., improper cleaning of tankers) (81).

In short, the products used in water fluoridation contain no radioactive materials. When other contaminants were detected, their concentrations were barely measurable and well below Canadian standards. Accordingly, their presence poses no known risk to human health.

4.2.4. Brominated compounds and trihalomethanes

Chlorine used in drinking water for disinfection is in an oxidized state, The potential for trihalomethane formation exists when chlorine, in its oxidized form, finds itself in the presence of appropriate precursors. Unlike chlorine, fluoride in drinking water is found in a reduced state. There are numerous studies that have shown that at the fluoride concentrations and the pH level of drinking water, dissociation of the fluoridated product is complete, so the fluoride is not present in a chemical form that is likely to induce an interaction with its precursors. In some cases, hypochlorous acid induces increased oxidation of certain heavy halogens. However, from a physical chemistry standpoint, chlorine does not have the capacity to oxidize fluoride since the latter is a lighter halogen with a higher electronegative potential (82).

5. COSTS AND BENEFITS OF WATER FLUORIDATION

One of the primary benefits of water fluoridation is that it reduces dental care expenditures, which involve considerable cost to society. It is estimated that the cost of dental care in Canada reached 9.9 billion dollars in 2006 (83), making it the second largest item in the health-care budget, after cardiovascular disease care. Based on this estimate, dental care costs for Quebeckers are approximately 2 billion dollars a year.

Quebec's health insurance board, the Régie de l'assurance maladie du Québec (RAMQ), and private insurers cover only a small segment of the population. Many low-income persons do not have access to dental insurance and are therefore deprived of these essential services.

According to the CDC, US$38 could be saved for every dollar invested in fluoridation in a community of 20,000 inhabitants (84). Another study, this one out of Scotland, estimates that the cost of providing dental care to children aged 4-5 and 11-12 could be reduced by half with fluoridation (85). Finally, a recent study suggests that Colorado residents who live in areas where water is fluoridated save $148 million each year (86).

There are no Quebec data to establish the cost-benefit ratio of water fluoridation. However, through extrapolation it is possible to estimate the potential reduction in dental care costs that would result from water fluoridation in Montreal. This evaluation is based on an estimated caries reduction rate of 25 % in children and on information obtained from the Quebec health insurance board concerning the cost of dental services to children aged 0-9. This analysis indicates that water fluoridation in Montreal would generate savings of $2-4 million per year to the Quebec health insurance board (87). This does not include related expenditures, such as hospitalization, general anesthesia and the cost of uninsured services, or costs associated with missed school and work days. It is estimated that 270,000 work days and 100,000 school days are lost each year in Canada due to dental problems and their treatment (88). Furthermore, every hospital-based dental treatment provided to a child that involves the administration of general anesthesia costs between $1,500 and $4,300 (89).

Finally, it has been established that water fluoridation delivers real economic benefits, even when the incidence of dental caries in the population is very low, that is, in the area of 0.05 decayed tooth surfaces per year (23).

6. OBSERVATIONS AND RECOMMENDATIONS

The purpose of water fluoridation is to prevent dental disease. Major international organizations such as the WHO and the CDC consider fluoridation to be a safe and effective public health measure to prevent tooth decay. Although health organizations largely concur on the safety of fluoridation, a small number of studies do raise questions concerning the link between fluoride and certain health problems. Consequently, in order to offer the population the benefits of water fluoridation, while minimizing potential problems, the INSPQ (Quebec public health institute) has taken into account Quebec's public health risk management framework, the *Cadre de référence pour la gestion des risques pour la santé dans le réseau québécois de la santé publique*, in developing its recommendations.

The INSPQ produced this advisory taking into account its mandate to improve health risk management practices (90). Quebec's public health risk management framework is designed to serve as a guide to public health professionals with respect to risk management and informed decision making. Its content is meant to be sufficiently broad to apply to a wide range of situations. However, it should not be seen as a "recipe book." The guiding principles it presents are meant to provide a framework for making decisions concerning water fluoridation. The seven guiding principles in this document are : empowerment of the community, equity, openness, the primacy of human health protection, prudence, scientific rigour, and transparency.

The INSPQ believes that the MSSS (Quebec department of health and social services) and its network should continue to build on these principles, which already guide the activities of public health professionals who are involved in the promotion of water fluoridation, in order to ensure a high level of quality, as well as compliance with ethical and scientific principles.

6.1. OBSERVATIONS

Overall, the scientific data currently available does not show that water fluoridation at concentrations deemed beneficial to dental health is harmful to humans. Nor have environmental studies revealed any harmful ecosystemic effects of fluoridation. It is important to note, however, that the vast majority of scientific reviews on fluoride have found methodological weaknesses in the epidemiological studies published to date. Consequently, such research needs to continue and must be improved from a methodological standpoint.

Water fluoridation is the safest, most effective and most economical public health measure for preventing and reducing dental caries. It benefits all citizens, regardless of their level of education, socio-economic status, age or ethnic background. Everyone can benefit from water fluoridation, especially the most vulnerable members of our society. Despite a lack of recent data on the prevalence of dental caries in Quebec children, the fact that the percentage of kindergarten children considered at risk for tooth decay has not declined in recent years suggests that current prevention methods are failing to reach the more vulnerable segments of the province's population.

Public health professionals have a responsibility to inform the public about the health benefits of fluoridation, the potential risks associated with this practice, and the measures taken to minimize such risks. Clear and transparent communication is one important success factor. The Institute's recommendations are consistent with those of major groups of international experts who continue to view fluoridation as an important public-health measure. Still, Quebec lags far behind the rest of North America in the implementation of this public health measure, and would have to undertake fluoridation throughout the province to attain a fluoridation status comparable with most other states and provinces. In other parts of the world, nations are fully committed to drinking water fluoridation or have adopted other means to increase their citizens' intake of fluoride. Fluoridated salt is one such option. Since the present document deals only with the fluoridation of drinking water, no scientific review of these other solutions was undertaken. However, even if we were to review these other options, the advantages of water fluoridation would in no way be diminished.

6.2. RECOMMENDATIONS

- The scientific data currently available do not justify a change in the current position of the MSSS (Quebec department of health and social services), with regard to fluoridation, given the dental health benefits of this practice. Consequently, the MSSS should maintain the water fluoridation program and its objectives, as described in the Quebec Public Health Program 2003-2012 and the PASDP (the provincial dental public health action plan 2005-2012), in accordance with the provisions of the Public Health Act adopted in December 2001.
- The MSSS should establish a monitoring system to periodically evaluate the prevalence of fluorosis and dental caries in the areas of Quebec where water is fluoridated and not fluoridated.
- The MSSS should establish a registry of water fluoride concentrations in Quebec municipalities, for the benefit of public health providers, health professionals and the public. This registry would provide relevant information to health professionals and parents of young children with regard to fluoride toothpastes and supplements, based on fluoride intakes from drinking water.
- The MSSS should maintain and, if necessary, adapt its water fluoridation monitoring program (Quebec norms and regulations on fluoridation of drinking water) in order to promote optimum caries reduction and protect the health of populations whose drinking water is artificially fluoridated.
- The MSSS should monitor scientific literature on the benefits and potential hazards of water fluoridation, in order to ensure that its recommendations to the public, as well as to health agencies and municipalities, are based on the best available information.
- The MSSS should ensure that drinking water fluoridation is subject to rigorous quality controls at all stages of the process, to ensure that the initial product, the transportation of chemicals, the waterline systems, and other aspects are of the highest quality.
- The MSSS should support the development of a research program which would identify the research options that are the most relevant to the Quebec context.

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APPENDIX 1

ORGANIZATIONS THAT SUPPORT WATER FLUORIDATION

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At the local and provincial levels

Ordre des dentistes du Québec
(Quebec Order of dentists)

Ordre des Hygiénistes dentaires du Québec
(Quebec order of dental hygienists)

College des médecins du Quebec
(Quebec college of physicians)

Québec Association of Pediatricians

Ordre des pharmaciens du Québec
(Quebec order of pharmacists)

Fédération des médecins omnipraticiens du Quebec
(Quebec Federation of family physicians)

Coalition Of Physicians for Social Justice

McGill University Faculty of Dentistry

Direction de la santé publique de Montréal
(Montreal Public Health Department)

Association des dentistes en santé publique du Québec
(Quebec association of public health dentists)

Montreal Children's Hospital Council of Community Pediatricians

Montreal Children' Hospital Child Development Program

Académie dentaire du Quebec
(Quebec dental academy)

Département de pédiatrie de l' Université de Montréal et de l'Hopital Ste-Justine
(St-Justine Hospital department of pediatics)

CHU Mère-Enfant de l' Hôpital Ste-Justine
(St-Justine Hospital university center)

Table de concertation des hygienistes dentaires en sante communautaire des régions Montreal, Laval, Laurentides et Lanaudiere

Observatoire montréalais des inégalités sociales et de la santé
(Montreal Research Centre on Social Inequalities in Health)

Département de médecine sociale et préventive de l'Université de Montréal
(University of Montreal department of social and preventive medicine)

Association dentaire pour les personnes en perte d'autonomie
(Dental association for disabled people)

Ministère de la Sante et des Services sociaux
(Quebec department of health and social services)

Ministère du Développement Durable et des parcs
(Quebec department of environment)

At the national level

Canadian Association of Dental Public Health

Canadian Dental Association

Canadian Dental Hygienist Association

Canadian Medical Association

Canadian Nurses Association

Canadian Pediatric Society

Canadian Public Health Association

Health Canada

At the international level

Academy of Dentistry International

Academy of General Dentistry

Academy for Sports Dentistry

Alzheimer's Association

America's Health Insurance Plans

American Academy of Family Physicians

American Academy of Nurse Practitioners

American Academy of Oral and Maxillofacial Pathology

American Academy of Orthopaedic Surgeons

American Academy of Pediatrics

American Academy of Pediatrie Dentistry

American Academy of Periodontology

American Academy of Physician Assistants

American Association for Community Dental Programs

American Association for Dental Research

American Association for Health Education

American Association for the Advancement of Science

American Association of Endodontists

American Association of Oral and Maxillofacial Surgeons

American Association of Orthodontists

American Association of Public Health Dentistry

American Association of Women Dentists

American Cancer Society

American College of Dentists

American College of Physicians-American Society of Internal Medicine

American College of Preventive Medicine

American College of Prosthodontists

American Council on Science and Health

American Dental Assistants Association

American Dental Association

American Dental Education Association

American Dental Hygienists' Association

American Dietetic Association

American Federation of Labor and Congress of Industrial Organizations

American Hospital Association

American Institute of Nutrition

American Legislative Exchange Council

American Medical Association

American Nurses Association

American Osteopathic Association

American Pharmaceutical Association

American Pharmacists Association

American Public Health Association

American School Health Association

American Society for Clinical Nutrition

American Society for Nutritional Sciences

American Student Dental Association

American Veterinary Medical Association

American Water Works Association

Association for Academic Health Centers

Association of American Medical Colleges

Association of Clinicians for the Underserved

Association of Maternal and Child Health Programs

Association of State and Territorial Dental Directors

Association of State and Territorial Health Officials

Association of State and Territorial Public Health

Australian National Health and Medical Research Council (NHMRC)

Australian Dental Association (ADA)

Australian Health Ministers' Conference

Australia New South Wales Department of Health

Nutrition Directors

British Dental Association

British Fluoridation Society

British Medical Association

Center for Science in the Public Interest

Child Welfare League of America

Consumer Federation of America

Children's Dental Health Project

Consumer Federation of America

Council of State and Territorial Epidemiologists

Delta Dental Plans Association

European Organization for Caries Research

Fédération Dentaire Internationale (FDI)

Federation of American Hospitals

Food and Nutrition Board

Great Britain Ministry of Health

Health Insurance Association of America

Hispanic Dental Association

Indian Dental Association (U.S.A.)

Institute of Medicine

International Association for Dental Research

International Association for Orthodontics

International College of Dentists

March of Dimes Birth Defects Foundation

Mayo Clinic

National Academy of Science

National Association of Community Health Centers

National Association of County and City Health Officials

National Association of Dental Assistants

National Association of Local Boards of Health

National Association of Social Workers

National Cancer Institute

National Confectioners Association

National Council Against Health Fraud

National Dental Assistants Association

National Dental Association

National Dental Hygienists' Association

National Down Syndrome Congress

National Down Syndrome Society

National Eating Disorders Association

National Foundation of Dentistry for the Handicapped

National Health Council

National Head Start Association

National Health Law Program

National Healthy Mothers, Healthy Babies Coalition

New Zealand Ministry of Health

Oral Health America

Pan American Health Organization

Public Health Association of Australia

Robert Wood Johnson Foundation

Royal College of Physicians (London)

Society for Public Health Education

Society of American Indian Dentists

Special Care Dentistry

The Children's Health Fund

The Dental Health Foundation (of California)

U.S. Department of Defense

U.S. Department of Veterans Affairs

U.S. Public Health Service

- U.S. Surgeon General
- Health Resources and Services Administration (HRSA)
- Centers for Disease Control and Prevention (CDC)
- Food and Drug Administration (FDA)
- Indian Health Service
- Health Resources and Services Administration (HRSA)
- National Institute of Dental and Craniofacial Research (NIDCR)

World Federation of Orthodontists

World Health Organization

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