The Role of Fluoride in the Prevention of Tooth Decay

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KEYWORDS

• Dental caries • Dental decay • Oral health • Fluorides • Primary prevention • Secondary prevention • Children

KEY POINTS

- Fluoride is the key to prevention of tooth decay.
- There are multiple fluoride modalities.
- Effectiveness and safety of fluoride depend on dose and concentration.
- Individual level fluoride use occurs at home and with professional application.
- Community level prevention occurs through fluoridation of water or salt.

INTRODUCTION

Dental Caries (Tooth Decay) in Children

Early childhood caries (ECC) is defined as the presence of one or more decayed (non-cavitated or cavitated lesions), missing (due to caries), or filled tooth surfaces in any primary tooth in a child younger than 6 years.[1] For children older than 6 years, there is no special category or definition of dental caries (see separate section/chapter on Dental Caries).

Fluoride is the Key to Prevention of Tooth Decay

Fluoride works to reduce the prevalence and severity of dental caries that requires restorative dental care, in preeruptive, posteruptive, systemic, and topical situations.

There are multiple mechanisms by which fluoride works:[2]

- Through reducing demineralization of enamel in the presence of acids produced by cariogenic bacteria in dental plaque breaking down fermentable carbohydrates,
- Through remineralization of early enamel caries, and
- Through inhibition of bacterial activity in dental plaque.

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Fluoride accumulates in dental plaque as fluoride ions from saliva, water, toothpaste and rinses, and professionally applied dental products. During daily tooth cleaning, some dental plaque remains, which provides the reservoir of fluoride for the remineralization of the tooth surface. High-fluoride modalities, such as fluoride varnish, combine with calcium in dental plaque to form globules of calcium fluoride, which dissociate slowly in the presence of plaque acids (lactic and pyruvic acids produced by bacterial breakdown of fermentable carbohydrates); this occurs because of the presence of a phosphate or protein-rich coating of the globular deposits of calcium fluoride, which releases bioavailable fluoride ions over a longer period of time.[3]

In addition, progression of caries in dentin toward the pulp may be inhibited or slowed by increased fluoride concentration within dentin. Fluoride can be incorporated into the developing tooth if a child swallows fluoride toothpaste or water in communities with fluoridated water.[4] There are multiple fluoride modalities, from programs in the community and schools to home-based approaches and professionally applied fluoride in dental offices and other settings.

Community Level Fluoride Programs

The world's population exceeds 7 billion, yet fewer than 1 billion have access to proven community-based water or salt fluoridation programs (and not all those with access take advantage of it). Such programs reduce the prevalence and severity of tooth decay, the most common chronic disease of children, which may be untreated in as much as 95% of the population of some countries.[5]

Water fluoridation

Water fluoridation is practiced in many countries throughout the world. As of 2012, more than 420 million people worldwide have access to either naturally fluoridated water (about 50 million) or water with adjusted fluoride concentrations at or near optimal (about 370 million).[6] In the United States, more than 211 million people—or about 75% of the population served by public water supplies—have access to fluoridated water.[7] A global systematic Cochrane review has shown that the introduction of community water fluoridation results in a 35% reduction in the mean number of decayed, missing, and filled primary teeth and a 26% reduction in the mean number of decayed, missing, and filled permanent teeth in children. Water fluoridation has also increased the percentage of children with no decay by 15%, according to the global Cochrane review.[8] Pediatric providers should encourage families to drink tap water where it is fluoridated.

Salt fluoridation

It has been estimated that between 40 million and 280 million people worldwide use salt fluoridation, mainly in European, South American, and Central American countries.[9] Salt fluoridation is sometimes suggested as an option for communities that have a low water fluoride concentration and have no possibility of implementing community water fluoridation. There are no salt fluoridation programs in the United States. The benefits and safety of salt fluoridation are similar to water fluoridation.[10] Although this is effective when no water fluoridation can be achieved, one has to be cautious if both options are available. It is recommended that a national fluoride program use only one of these community-based approaches (water or salt) to minimize the risk for dental fluorosis in young children with developing teeth.[11]

School-Based Fluoride Programs

Fluoridated milk

Although not practiced in the United States, fluoridated milk may be beneficial to schoolchildren, contributing to a substantial reduction in dental caries in primary

teeth.[12] Successful milk fluoridation programs have been evaluated in Japan, Scotland, Israel, Hungary, and several other countries, including a study in Louisiana, USA in the 1950s.[13]

Fluoride mouthrinse

Because of the natural swallowing reflex, most children younger than 6 years may not be able to resist swallowing a mouthrinse. For children older than 6 years, regular use of alcohol-free fluoride mouthrinse under supervision has been shown to result in a large reduction in tooth decay in children's permanent teeth.[14] The margin of safety for acute toxicity with school-based 900-ppm fluoride mouthrinse is wide (10 mL contains 9 mg fluoride), which is more than 10 times lower than the probably toxic dose for a 6-year-old child of average weight (20 kg).[6] In communities with low exposure to fluoride in water, school-based fluoride rinsing programs are recommended, but their adoption should be based on the cost of implementation and the caries status of the community.[6]

Home-Based Fluoride

Dietary fluoride supplements

Prescription fluoride supplements (fluoride tablets or drops) have been shown to be effective in reducing caries incidence in permanent teeth, when used as prescribed.[15] However, fluoride tablets and drops have limited application as a public health measure due to poor adherence to the recommended daily schedule,[6] and evidence for ECC prevention with fluoride tablets and drops is insufficient.[16] In the United States, dietary fluoride supplements may be prescribed (with or without vitamins) for children at high risk for caries; the daily dose depends on age and fluoride concentration of the water supply.[17] However, fluoride supplements are not recommended for infants younger than 6 months (or without teeth) or for any children from where the fluoride in the water contains greater than 0.6 mg/L of fluoride (**Table 1**). Where water supplies contain less than 0.3 mg/L fluoride, the following are recommended:

- No fluoride tablets should be prescribed before the age of 6 months;
- Between 6 months and 3 years, prescribe 0.25 mg fluoride per day;
- Between 3 and 6 years 0.50 mg fluoride per day; and
- Between 6 and 16 years 1 mg fluoride per day.

For water supplies with 0.3 to 0.6 mg/L fluoride, the following are recommended:

- Fluoride drops or tablets should not be prescribed before the age of 3 years;
- Between 3 and 6 years, prescribe 0.25 mg of fluoride per day; and
- Between 6 and 16 years 0.5 mg fluoride per day.

Fluoride toothpaste

There is strong evidence that twice-daily use of fluoride toothpaste has a significant caries-reducing effect in young permanent teeth compared with a placebo.[18] Strong evidence suggested a dose–response relationship with enhanced caries protection from toothpastes with 1500 ppm of fluoride compared with formulations with 1000 ppm of fluoride in young permanent teeth following daily use.[19] However, only 1000 to 1100 ppm fluoride toothpaste is currently available in the United States[20] without a prescription. Nevertheless, daily tooth brushing with fluoride toothpaste, even at less than optimal fluoride dosage, from the time of eruption of the first tooth must be regarded as the best clinical practice today, based on moderate quality of evidence.[18] Toothpaste should be applied by the parent, with only a smear for children younger than 3 years and a pea-size amount for those older than 3 years (**Fig. 1**A, B). Toothpaste should be spit out after brushing, without water for rinsing. In addition,

Table 1
Fluoride supplement (tablets and drops) dosage schedule 2010 (Approved by the American Dental Association Council on Scientific Affairs)

	Fluoride Ion Level in Drinking Water (ppm)[a]		
Age	**<0.3**	**0.3–0.6**	**>0.6**
Birth–6 mo	None	None	None
6 mo–3 y	0.25 mg/d[b]	None	None
3–6 y	0.50 mg/d	0.25 mg/d	None
6–16 y	1.0 mg/d	0.50 mg/d	None

Important Considerations When Using Dosage Schedule: (1) If fluoride level is unknown, drinking water should be tested for fluoride content before supplements are prescribed. For testing of fluoride content, contact the local or state health department. (2) All sources of fluoride should be evaluated with a thorough fluoride history. (3) Patient exposure to multiple water sources may complicate proper prescribing. (4) Ingestion of higher than recommended levels of fluoride by children has been associated with an increased risk of mild dental fluorosis in developing, unerupted teeth. (5) To obtain the benefits from fluoride supplements, long-term compliance on a daily basis is required.

[a] 1.0 ppm = 1 mg/L.

[b] 2.2 mg sodium fluoride contains 1 mg fluoride ion.

From American Dental Association. Oral Health Topics. Fluoride: Topical and Systemic Supplements. Available at: http://www.ada.org/en/member-center/oral-health-topics/fluoride-topical-and-systemic-supplements Accessed on May 23, 2018;

there are toothpastes on the market that do not have fluoride; pediatric providers should discourage patients from using these.

Prescription strength fluoride toothpaste

There is a strong evidence base for the use of high-fluoride toothpastes (5000 ppm fluoride) in groups at a greater risk of caries.[21] It is recommended to restrict its use in those younger than 6 years to cases where the risk of severe morbidity caused by caries is greater than that of aesthetically objectionable fluorosis. For children younger than 9 years who are at risk for developing dental fluorosis, it is recommended that the toothpaste be rinsed out with water after using high-fluoride toothpaste, whereas when using regular fluoride toothpaste, it is recommended that the toothpaste be spit out after use, rather than rinsed with water.

Fluoride mouthrinse

Mouthrinses for daily home use contain 225 ppm of fluoride, as opposed to the higher 900 ppm of fluoride concentration used in weekly school-based programs. Fluoride

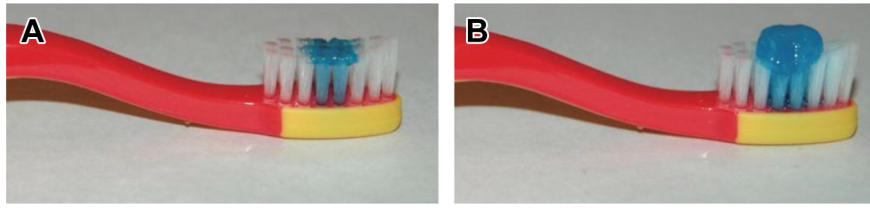

Fig. 1. Toothbrushes with fluoride toothpaste: smear/rice-size amount; pea-size amount. (*A*) Smear amount of toothpaste. (*B*) Pea-sized amount of toothpaste. (*Data from* American Dental Association. Oral health topics. Fluoride: topical and systemic supplements. Available at: http://www.ada.org/en/member-center/oral-health-topics/fluoride-topicaland-systemic-supplements. Accessed May 23, 2018.)

mouthrinses are reserved for children older than 6 years who have outgrown the swallowing reflex and who are at moderate or high caries risk, regardless of fluoride level of the drinking water. It is recommended to rinse for 1 to 2 minutes and spit out the rinse, rather than rinse with water afterward. Benefits of caries prevention from fluoride rinsing were found with and without prior toothbrushing.[22]

Professionally Applied Topical Fluoride

Fluoride gels

Professionally applied high-concentration fluoride gels have been widely used by dental professionals in dental offices to prevent tooth decay in children and adults at high risk for tooth decay, whether in a fluoridated or nonfluoridated area. The application of fluoride gel (12,300 ppm of fluoride as acidulated phosphate fluoride) results in a large reduction in tooth decay in both permanent and primary teeth.[23] Gels are applied to the teeth using gel trays in the dentist's office, which must stay on the patient's teeth for approximately 4 minutes, with adequate suction to reduce swallowing of the gel. Precautions that should be undertaken include the following:[22]

1. Using only the required amount of the fluoride solution or gel to perform the treatment adequately,
2. Positioning the patient in an upright position,
3. Using efficient saliva aspiration or suctioning apparatus, and
4. Requiring the patient to expectorate thoroughly on completion of the fluoride application.

The use of these procedures has been shown to reduce the amount of inadvertently swallowed fluoride to less than 2 mg, which can be expected to be of little consequence. However, the use of these gels has mostly been replaced by the use of fluoride varnish.

Fluoride varnish

Varnishes and gels are equally effective at preventing caries.[24] Increasingly, varnishes are used instead of gels due to the ease of application and low risk from ingestion of large doses, especially for younger children.

Professionally applied 5% sodium fluoride varnish (22,600 ppm of fluoride), in single doses of up to 9 mg fluoride, can remineralize early enamel caries[25] and prevent the need for dental restorations. Varnishes are brushed onto clean, dry teeth, in the dentist's office, the medical office, and increasingly in other sites with children at high caries risk, such as WIC or Head Start. The application takes about 1 minute, and the varnish sets quickly. To keep the varnish on the teeth for several hours, patients are told to eat soft foods and avoid brushing and flossing for the remainder of the day. Fluoride varnish has been shown to be effective in the prevention of caries in both primary and permanent teeth. The interval for frequency of application of fluoride varnish varies depending on the risk of the patient—more frequently for children with higher risk.[26] Although use of fluoride varnish for caries prevention is technically considered an "off-label" use (it is US Food and Drug Administration [FDA] approved for tooth sensitivity), there is a robust evidence base for the efficacy of varnish at preventing caries.[27,28] Varnish can be reapplied every 3 to 6 months, depending on risk, and no cases of fluorosis have been linked to excessive varnish use.

Application of fluoride varnish by primary care providers The FDA has approved fluoride varnish products as medical devices to be used as cavity liners and for the treatment of hypersensitive teeth, but they can be used off-label as caries-preventive agents. Because of its safety, fluoride varnish can be applied without specialized

equipment (eg, compressed air or suction) by trained dental and medical personnel (doctor, nurse practitioner, physician assistant, registered nurse, licensed practical nurse, certified medical assistant) to at-risk children and adults in dental and medical offices as well as in a variety of nonmedical clinic venues.[29]

Young children tend to see primary care physicians (PCPs) far more frequently than dentists. In the United States, the American Academy of Pediatrics recommends that a child see PCPs 11 times for a checkup by the age of 2 years. It therefore makes sense to use PCP visits to address oral health in young children. The utilization of PCPs as a first-line provider of preventive dental services in improving children's oral health is an innovative approach that facilitates the integration of the dental and medical communities and oral health inclusion into primary health care. In addition, because medical providers typically have higher rates than dentists of participation in public-funded health care, Medicaid, they can provide preventive oral health services to low-income children as part of well-child care while referring to dentists those who need more complex restorative care.[30]

The potential success of such approach was demonstrated in a program called Into the Mouths of Babes, initiated in North Carolina in 2000. In this program physicians were reimbursed by Medicaid to conduct dental screenings and apply fluoride varnish in children younger than 3 years and counsel parents. This program demonstrated the sustainable long-term success of this initiative.[31] The economic impact of the program demonstrated 32% lower total Medicaid expenditures for hospital episodes.[32]

Combination of fluoride modalities

Topical fluorides (mouthrinses, gels, or varnishes) used in addition to fluoride toothpaste achieve a modest reduction in caries compared with toothpaste used alone.[33] With the exception of fluoride toothpaste, which is the most widely used topically applied fluoride worldwide, topical fluorides are usually recommended for individuals or populations who are considered to be at moderate or high caries risk, after taking into account other exposures to fluoride.[6] Regardless of the type of professionally applied topical fluoride treatments, the results of clinical trials clearly indicate that the benefits of topical fluoride applications are related to the number of treatments and frequency of use.[5]

Preference for fluoride modalities

Fluoride toothpastes, in comparison with mouthrinses or gels, seem to have a similar degree of effectiveness for the prevention of dental caries in children. There is no clear suggestion that fluoride varnish is more effective than mouthrinses and the evidence for the comparative effectiveness of fluoride varnishes and gels and mouthrinses and gels is inconclusive.[34] Therefore, when a child is found to have tooth decay or is deemed to be at high risk for decay, then recommendations to the parents/guardians should be made for them to supervise twice daily use of age-appropriate amounts of fluoride toothpaste for their child, while recommending and obtaining consent to apply fluoride varnish by the health care professional. Note that fluoride mouthrinses for home use are only recommended for children who are able to spit out the rinse and not swallow it.

Frequency of Professionally Applied Fluoride Use

For dental professionals, it is recommended that new patients with active caries, regardless of age, be given an initial series of 4 topical fluoride applications within a period of 2 to 4 weeks. If desired, the initial application can be preceded by a thorough dental prophylaxis (professional cleaning) and the remaining 3 applications of the initial treatment series should be preceded by tooth brushing to remove plaque and oral debris. It should be obvious that this series of treatments can be very conveniently

combined with plaque control, dietary counseling, and initial restorative programs that the dental provider has devised for these patients. Following this initial series of treatments, the patient should be given single, topical applications at intervals of 3, 6, or 12 months, depending on the patient's caries status.[35]

Comparing fluoride varnish and dental sealants

Dental sealants, applied by dental professionals, are recommended to seal pits and fissures in the biting surfaces of primary and permanent molars before them showing overt signs of tooth decay. The oral health objectives in Healthy People 2020 include increasing the proportion of children aged 3 to 5 years who have received dental sealants on one or more of their primary molar teeth, as well as increasing the proportion of children aged 6 to 9 years who have received dental sealants on one or more of their permanent first molar teeth and increasing the proportion of adolescents aged 13 to 15 years who have received dental sealants on one or more of their permanent molar teeth.[36] Both dental sealants and fluoride varnish are recommended to provide maximum prevention of tooth decay for those at risk for tooth decay. Fluorides mainly work to prevent decay on the smooth surfaces of teeth, whereas sealants prevent caries on the nonsmooth pit and fissures. Although it should not be a choice between sealants and fluoride varnish, in a community-based oral health program targeted at 6- to 7-year-old children at high caries risk, the application of fluoride varnish as a caries-preventive measure resulted in caries prevention that was not significantly different from that obtained by applying and maintaining dental sealants after 36 months.[37]

Methods to increase compliance with fluoride modalities

A growing number of parents are refusing topical fluoride for their children during preventive dental and medical visits.[38] This refusal is based on readily available erroneous information on the Internet promulgated by antifluoridation rhetoric. Arguments and unproven claims that fluoride causes a multitude of conditions and diseases, such as AIDS, Alzheimer disease, cancer, Down Syndrome, genetic damage, heart disease, lower intelligence, kidney disease, osteoporosis, and bone fracture, have been addressed in authoritative evidence-based information, most notably by the American Dental Association in Fluoridation Facts (2018). It has been proposed that there will be greater compliance with recommended fluoride varnish regimens in families who receive motivational interviewing as compared with families receiving traditional education and counseling.[39]

A focus group study on attitudes to fluoridation[40] made the following conclusions:

- Fluoride advocates should preserve individual choice wherever possible.
- Individual choice takes a back seat, if there is a significant demonstrable benefit and safety to the wider community.
- The scientific evidence indicates that fluoridation offers such benefit and more than adequate safety.

In addition, building trust is essential. The following recommendations were made:

- Experts and advocates need to acknowledge that concerns about fluoride exist and should treat them seriously.
- Simply trying to correct factual misunderstandings without addressing underlying concerns actually increases mistrust.
- The preferred approach should not focus on correcting factual misconceptions or emphasizing positive messages, but on understanding public concerns and building on common ground.

Biomarkers of fluoride exposure

Although fluoride concentrations in plasma, saliva, and urine have some ability to assess fluoride exposure, present data are insufficient to recommend using fluoride concentrations in these body fluids as biomarkers of contemporary fluoride exposure for individuals. Daily fluoride excretion in urine can be considered a useful biomarker of contemporary fluoride exposure for groups of people, and standards for urinary fluoride excretion indicating low, optimal, and high fluoride exposure are available.[6]

Safety of Fluoride

Overall, in the doses listed here, fluoride is very safe. Based on a lowest-observed-adverse-effect level of 0.10 mg/kg/d for moderate enamel fluorosis and an uncertainty factor of 1, a Tolerable Upper Intake Level (UL) of 0.10 mg/kg/d on a daily basis over extended periods of time was established for infants, toddlers, and children through 8 years of age.[41] This should not be interpreted as a limit to prevent acute toxicity, which is much higher in the order of 5 mg/kg or 50 times higher; nor should it be interpreted as a limit for occasional exposure, such as when fluoride varnish is applied. The UL of fluoride is age/weight dependent; for young children the UL varies from 0.7 mg/d to 2.0 mg/d depending on body weight, and because the crowns of permanent teeth have already formed by the age of 9 years, other than the wisdom teeth, for children older than 9 years of age and adults, the daily UL is 10 mg (**Table 2**). Comparisons of fluoride concentration, volume/weight, and total fluoride dose of various topical fluoride products for home use and for professional use can be found in **Tables 3** and **4**.

The most common side effect of chronic high fluoride intake in children younger than 9 years is dental fluorosis. Nonsevere forms of dental fluorosis are not detrimental to health and in fact the milder forms of dental fluorosis have been shown to be associated with increased resistance to dental caries.[42]

Dental Fluorosis

Dental fluorosis is defined as a change in the mineralization of the dental hard tissues caused by long-term ingestion of fluoride during the period of tooth development before eruption into the mouth (first 8 years of life for most permanent teeth excluding third molars). Once the tooth erupts, dental fluorosis refers to a

Table 2
Table of adequate intake and tolerable upper level for fluoride intake by age/weight

Age Group	Reference Weights kg (lbs)[a]	Adequate Intake (mg/d)	Tolerable Upper Intake (mg/d)
Infants 0–6 mo	7 (16)	0.01	0.7
Infants 6–12 mo	9 (20)	0.5	0.9
Children 1–3 y	13 (29)	0.7	1.3
Children 4–8 y	22 (48)	1.0	2.2
Children 9–13 y	40 (88)	2.0	10
Boys 14–18 y	64 (142)	3.0	10
Girls 14–18 y	57 (125)	3.0	10
Men 19 y and older	76 (166)	4.0	10
Women 19 y and older	61 (133)	3.0	10

[a] Value based on data collected during 1988 to 1994 as part of the Third National Health and Nutrition Examination Survey (NHANES III) in the United States.

From American Dental Association. Fluoridation Facts; 2018. p 45: Table 2;

Table 3
Professionally applied topical fluoride

Agent	Fluoride Concentration	ppm F (Approx.)	Volume or Weight	Total F Dose	Comments	Time/ Frequency
F Varnish (5% NaF)	2.25%	22,600	0.25 mL	5.65 mg	For <6 y of age	1 min; 3/y
F Varnish (5% NaF)	2.25%	22,600	0.4 mL	9 mg	For >6 y of age	1 min; 3/y
8% SnF_2	1.936%	19,360	5 mL	96.8 mg	Seated, suction, spit	4 min; 2/y
APF Office Gel	1.23%	12,300	5 mL	61.5 mg	Seated, suction, spit	4 min; 2/y
NaF gel/foam (2%)	0.90%	9000	5 mL	45 mg	Seated, suction, spit	4 min; 2/y

range of visually detectable changes in enamel. Dental fluorosis, originally described as mottled enamel, may also be called enamel fluorosis. Changes range from barely visible lacy white markings in milder cases to converged opaque areas, browning, and pitting of the teeth in severe forms. Dental fluorosis cannot develop in teeth after the teeth have formed; once evident, fluorosis does not progress in severity.[43]

Fewer than 1% of individuals in the United States have severe dental fluorosis, a condition recognized as an adverse health effect.[44] The prevalence of severe enamel

Table 4
Home use of topical fluoride

Agent	Fluoride Concentration	ppm F (Approx.)	Volume or Weight	Total F Dose	Comments	Time/ Frequency
Toothpaste (0.22% NaF)	0.10%	1000	1 g	0.1 mg	6 mo to 3 y: smear or rice-size amount	2/d
Toothpaste (0.22% NaF)	0.10%	1000	1 g	0.25 mg	3–6 y: pea-size amount	2/d
Toothpaste (0.22% NaF)	0.10%	1000	1 g	1 mg	Older than 6 y: spit after use	2/d
Prescription toothpaste (1.1% NaF)	0.50%	5000	1 g	5 mg	<9 y: rinse after use	2/d
Home gel (0.4% SnF_2)	0.097%	970	1 g	1 mg	Spit after use	1/d
Mouthrinse (0.05% NaF)	0.025%	225	10 mL	2.25 mg	Spit after use	1/d
Fluoridated water	0.0001%	1	1 L	1 mg	—	Several/d

Adapted from Pollick HF. Topical fluoride therapy. In: Harris NO, Garcia-Godoy F, Nathe CN, editors. Primary Preventive Dentistry (Subscription), 8th Ed., ©2014. Reprinted by permission of Pearson Education, Inc., New York, New York.

fluorosis is very low (near zero) at fluoride concentrations in drinking water below 2 mg/L.[45] (NRC 2006) Nonfluorotic alteration in the appearance of teeth, such as enamel hypoplasia, may be confused with dental fluorosis.[46]

Public health organizations work to keep the dose of fluoride to the minimal necessary while still providing benefit. The recommended fluoride concentration of drinking water was changed in 2015 to a standard 0.7 mg/L across the United States, in part because of higher prevalence of dental fluorosis seen in the NHANES reports.[47] Similarly, the schedule of recommended doses of prescription fluoride supplements was changed in 1994 as a result of evidence of increased dental fluorosis from the earlier recommendation on supplements.[48]

Acute Fluoride Toxicity

Acute fluoride toxicity presents with symptoms of nausea and vomiting, muscle spasms, abdominal pain, possibly leading to coma, convulsions, and cardiac arrhythmias. It can occur with inappropriate and excessive ingestion of fluoride products, such as multiple prescription dietary fluoride supplements at one time, or swallowing excess topical high concentration fluoride applications in a dental office, such as from professionally applied fluoride gels in trays without adequate suction and posttreatment spitting.[45] Immediate action must be taken in such cases.[49]

Chronic fluoride toxicity presents with symptoms and signs of stiffness and pain in the joints and muscles from skeletal fluorosis. This usually results from fluoride exposure over a prolonged period of many years in communities where the water supply (or personal wells) contains a high concentration of fluoride.[50] Most commonly this occurs in areas with naturally fluoridated water. To this effect, the US Environmental Protection Agency has set primary (4 mg/L) and secondary (2 mg/L) maximum contaminant levels for naturally occurring fluoride in drinking water.[51] As a result, community water systems must notify customers, if the secondary maximum contaminant level is exceeded, so that parents and caregivers can see to it that children younger than 9 years do not consume that water on a regular basis, to prevent the development of moderate and severe dental fluorosis.[52] In addition, regulations in the United States stipulate that individual wells must be tested regularly by the owner.[53]

Recommendation on the Use of Infant Formula

There is weak evidence that the fluoride in infant formula reconstituted with fluoridated water could be a cause of enamel fluorosis, as other mechanisms, including swallowing fluoride toothpaste during the tooth developing years, could explain the observed association.[54] When dentists (and other PCPs) advise parents and caregivers of infants who consume powdered or liquid concentrate infant formula as the main source of nutrition, they can suggest the continued use of powdered or liquid concentrate infant formulas reconstituted with optimally fluoridated drinking water while being cognizant of the potential risks of enamel fluorosis development.[55] The Centers for Disease Control states “To lessen this chance, parents may choose to use low-fluoride bottled water some of the time to mix infant formula. These bottled waters are labeled as de-ionized, purified, demineralized, or distilled and are without any fluoride added after purification treatment (FDA requires the label to indicate when fluoride is added).”[56]

Since the USPHS recommendation for optimizing community water supplies to 0.7 ppm of fluoride was instituted, dental fluorosis due to reconstituting infant formula with fluoridated water is expected to be less of an issue.[57]

Silver diamine fluoride

A different fluoride compound is available for secondary prevention and arrest of dentinal caries where a cavity has already been established in a tooth. Silver diamine fluoride (SDF) is effective in arresting dental caries. SDF can arrest caries in the inner dentine of primary and permanent teeth and prevent caries recurrence after treatment. The American Academy of Pediatric Dentistry supports the use of 38% SDF for the arrest of cavitated caries lesions in primary teeth as part of a comprehensive caries management program.[58] SDF is not recommended for primary prevention of caries, although when applied to carious lesions, studies have shown primary prevention in other sites in the mouth.[59] Only specifically trained professionals should apply SDF because of persistent black staining of the carious lesion and soft tissues beyond the cavity, including lips and operator's fingers and clothing. A protocol has been developed for the use of SDF.[60] See **Box 1**[61] for a summary of evidence of effectiveness.

Recommendations for Fluoride Use to Prevent Dental Caries in Children

Despite many similarities, recommendations for the use of topical fluoride vary worldwide by different groups in different countries. The following represent a sample of recommendations for fluoride use to prevent dental caries in children.

American Academy of Pediatrics

For all children (at low or high caries risk)[62]:

Toothpaste: starting at tooth emergence (smear of paste until age 3 y, then pea-size amount)

Fluoride varnish: every 3 to 6 months starting at tooth emergence.

Community water fluoridation.

Dietary fluoride supplements: if drinking water supply is not fluoridated (Note: The American Dental Association does not recommend dietary fluoride supplements for children at low caries risk).

Box 1
American Academy of Pediatric Dentistry: summary of evidence of effectiveness of fluoride

1. There is confirmation from evidence-based reviews that fluoride use for the prevention and control of caries is both safe and highly effective in reducing dental caries prevalence.
2. There is evidence from randomized clinical trials and evidence-based reviews that fluoride dietary supplements are effective in reducing dental caries and should be considered for children at caries risk who drink fluoride-deficient (<0.6 ppm) water.
3. There is evidence from randomized controlled trials and meta-analyses that professionally applied topical fluoride treatments, such as 5% sodium fluoride varnish or 1.23% fluoride gel preparation, are efficacious in reducing caries in children at caries risk.
4. There is evidence from meta-analyses that fluoridated toothpaste is effective in reducing dental caries in children, with the effect increased in children with higher baseline level of caries, higher concentration of fluoride in the toothpaste, greater frequency in use, and supervision. Using no more than a smear or rice-size amount of fluoridated toothpaste for children younger than 3 years may decrease risk of fluorosis. Using no more than a pea-size amount of fluoridated toothpaste is appropriate for children aged 3 to 6 years.
5. There is evidence from randomized clinical trials that 0.2% sodium fluoride mouthrinse and 1.1% sodium fluoride brush-on gels/pastes also are effective in reducing dental caries in children.

From American Academy of Pediatric Dentistry: guidelines on fluoride therapy. 2014. Available at: http://www.aapd.org/media/policies_guidelines/g_fluoridetherapy.pdf. Accessed January 2, 2018.

For children at high caries risk, in addition to recommendations for all children:
Over-the-counter mouthrinse: starting at age 6 years if the child can reliably swish and spit

American Dental Association Council on Scientific Affairs Expert Panel on Topical Fluoride Caries Preventive Agents[63]

For all children: twice daily use of age-appropriate amount of fluoride toothpaste.
For those at risk for caries:
For children younger than 6 years:
- Only 2.26% fluoride varnish at least every 3 to 6 months is recommended

For children older than 6 years:
- Professionally applied 2.26% fluoride varnish at least every 3 to 6 months
  - Or 1.23% fluoride (acidulated phosphate fluoride) gel, at least every 3 to 6 months
- Home use of a prescription-strength, home-use 0.5% fluoride gel or paste twice daily
  - Or 0.09% fluoride mouthrinse daily

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Population-based risk factors[64]:
- Low-income children (eg, enrolled in Head Start, WIC, free/reduced lunch program, Medicaid or SCHIP eligible, or other programs serving low-income children)
- Children with special health care needs

Children younger than 2 years:
Toothpaste:
- Encourage parents and caregivers to take an active role in brushing their children's teeth once the first tooth erupts
- Educate parents and caregivers on proper fluoride toothpaste use
- Brush children's teeth with fluoride toothpaste twice daily
- Use a smear of fluoride toothpaste
- Do not rinse after brushing

Varnish:
- Apply every 3 to 6 months

Children aged 2 to 6 years:
Toothpaste:
- Encourage parents and caregivers to take an active role in brushing their children's teeth
- Educate parents and caregivers on proper fluoride toothpaste use
- Brush children's teeth with fluoride toothpaste, or assist children with tooth brushing, twice a day
- Use no more than a pea-size amount of fluoride toothpaste
- Children should spit out excess toothpaste
- Do not rinse after brushing

Varnish:
- Apply every 3 to 6 months

Academy of Nutrition and Dietetics

It is the position of the Academy of Nutrition and Dietetics to support optimal systemic and topical fluoride as an important public health measure to promote oral health and overall health throughout life.[65]

Box 2
Table of caries risk assessment

Age 6 years and older. Available at: http://www.ada.org/~/media/ADA/Science%20and%20Research/Files/topic_caries_over6.ashx

Age 6 years and older (For Dental Providers). Available at: http://www.aapd.org/media/policies_guidelines/g_cariesriskassessment.pdf

Younger than 6 years. Available at: http://www.ada.org/~/media/ADA/Member%20Center/FIles/topics_caries_under6.pdf?la=en

Younger than 3 years (for physicians and other nondental health care providers). Available at: http://www.aapd.org/media/policies_guidelines/g_cariesriskassessment.pdf

For 0 to 5 years of age (for dental providers). Available at: http://www.aapd.org/media/policies_guidelines/g_cariesriskassessment.pdf

Recommendations to Reduce Dental Fluorosis

1. Defer the use of fluoride toothpaste until a child is aged between 18 and 36 months unless the child has been assessed as being at increased risk of developing caries (Forum on Fluoridation, 2002; Health Canada, 2010; Australian Research Centre for Population Oral Health, 2012).[4]
2. Use a "smear" of fluoride toothpaste (0.1 mg) for all children younger than 3 years and a pea-size amount (0.25 mg) for those older than 3 years (SIGN 2014; Public Health England, 2014; ADA Council on Scientific Affairs, 2014).
3. Although not available in the United States, some countries recommend the use of low-fluoride toothpaste for young children (EAPD, 2009; Australian Research Centre for Population Oral Health, 2012). The 2012 Australian guidelines recommend the use of low-fluoride toothpaste (500–550 ppm) for children aged 18 months to 5 years.[66]

Other than dental sealants that have been shown to effectively prevent pit and fissure caries (see John Timothy Wright's article, "The Burden and Management of Dental Caries in Older Children," in this issue) (**Box 2**), nonfluoride agents, such as chlorhexidine and xylitol wipes rinse may serve as adjunctive therapeutics for preventing, arresting, or even reversing dental caries, but they are not substitutes for proven fluoride modalities for caries prevention.[67,68]

SUMMARY

Much has been researched and written about fluoride and the prevention of tooth decay (dental caries). There is overwhelming evidence and consensus that fluoride is of paramount importance to prevent tooth decay. In addition to twice daily home use of over-the-counter fluoride toothpaste in the appropriate amounts for different aged children, the most common use is fluoridation of water (or salt), which is effective to reach large number of children simultaneously (population approach). Certain children, mostly those at higher risk for caries, however, need additional fluoride. Numerous modalities are available and each has its advantages and disadvantages. Communication and consultation with dentists will usually develop the best strategy for each individual child. Although any population and/or individual approach to affect health in a positive manner carries risk, fluoridation can result in various levels of dental fluorosis while teeth are developing; it is generally accepted that tooth decay prevention takes precedence. Therefore, as a general recommendation, it is felt that children

Box 3
Further resources

Application of fluoride varnish (link to Youtube video)
Bertness J, Holt K, editors. Fluoride varnish: a resource guide. 2nd edition. Washington, DC: National Maternal and Child Oral Health Resource Center. 2016.
https://www.mchoralhealth.org/PDFs/ResGuideFlVarnish.pdf
https://www.youtube.com/watch?v=OzM4UQxP67Q

Application of SDF (link to Youtube video)
http://www.astdd.org/www/docs/sdf-fact-sheet-09-07-2017.pdf

Abbreviation: SDF, silver diamine fluoride.

should have access to and drink fluoridated water and use recommended amounts of fluoride toothpaste on a twice-daily basis to promote oral health (**Box 3**).

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