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Tiny Teeth, Powerful Protection; Fluoride Dentifrices in Children

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Abstract

Background: Dental caries remains one of the most prevalent oral diseases affecting children, and effective preventive strategies are essential for maintaining oral health. Fluoride dentifrices are considered a fundamental component of caries prevention because they provide topical fluoride while simultaneously facilitating mechanical removal of dental biofilm. Their effectiveness is primarily attributed to inhibition of enamel demineralization, enhancement of remineralization, and modulation of cariogenic bacterial activity.

Aim: This review aims to evaluate the role of fluoride dentifrices in pediatric dentistry, with emphasis on their composition, fluoride compounds, mechanism of action, concentration-dependent efficacy, clinical benefits, safety, and age-specific recommendations.

Methods: A systematic review of the available literature was undertaken to assess evidence regarding fluoride-containing dentifrices used in children. Relevant literature addressing fluoride formulations, concentrations, anticaries efficacy, remineralization, safety, dental fluorosis, and clinical recommendations was considered.

Results: Evidence indicates that regular use of fluoride dentifrices significantly contributes to the prevention and control of dental caries in both primary and permanent dentitions. Sodium fluoride, sodium monofluorophosphate, stannous fluoride, and amine fluoride are among the commonly used fluoride compounds. The anticaries effect is influenced by fluoride concentration, frequency of brushing, duration of exposure, and fluoride availability in the oral environment. However, excessive ingestion during tooth development may increase the risk of dental fluorosis, highlighting the importance of age-appropriate fluoride concentration, toothpaste quantity, and parental supervision.

Conclusion: Fluoride dentifrices represent an accessible and effective topical fluoride-delivery system for children. Their appropriate use, tailored according to age and caries risk, can provide substantial caries-preventive benefits while minimizing the risk of fluorosis. An evidence-based approach by pediatric dental professionals is essential for optimizing their safe and effective use.

Keywords: Fluoride Dentifrices, Dental Caries, Fluoride Concentration, Remineralization, Demineralization, Dental Fluorosis, Caries Prevention, Fluoride Compounds

Introduction

Dental caries being a global health problem can be brought under control with fluoride dentifrices. It was hypothesized that fluoride inhibits tooth decay by rendering the outer layer of the tooth less soluble to acid [1]. Since the beginning of the twentieth century, fluoride has been known to have anti-caries effects and to reduce both the incidence and severity of dental caries [2].

Fluoride (F) is added to many dental care products as well as in drinking water to prevent dental decay. It is admitted that tooth brushing with fluoridated toothpaste is a fundamental cornerstone for the prevention of early childhood caries. It protects against caries by generating fluoridated apatite more resistant to acids produced by oral bacteria, increasing the remineralization process, and inhibiting bacterial enolase activity[3].

Toothpaste is a complex mixture of components, each with a specific role to play. It is a high-viscosity paste, and the main components are water (20–40%) and an abrasive (50%). [2]

Excessive F intake (especially from a dentifrice) during the formation of permanent teeth (i.e., particularly at 2–3 years of age) can lead to dental fluorosis. [4]

Fluoride dentifrices combine the mechanical removal or disruption of dental biofilm with the therapeutic effects of F on the processes of demineralization and remineralization of dental tissues .[4]

Two important factors are-

- The initial interaction of relatively high concentrations of fluoride with the tooth surface and plaque during application and
- The retention of fluoride in oral fluids after application [1] .

Among all fluoride delivery vehicles, fluoridated toothpaste remains the most accessible and widely used method for caries prevention . [5]

Historic Perspective

Between 3000–5000 BC, Egyptians prepared early toothpaste-like dental creams using powdered oxen hooves, myrrh, burned eggshells, pumice, and water.[1] By 500 BC, toothpaste use was recorded in India and China. In the early 19th century, fluoride was known to occur in calcified tissues.[7]

In 1900, Stefano Chiaia observed brown-spotted teeth that were highly resistant to caries.[8] In 1915, McKay and Black described the phenomenon of spotted enamel.[8] In 1955, fluoride became the first active principle added to toothpaste, and Crest launched the first clinically proven fluoride toothpaste. Fluoride toothpastes subsequently received ADA approval.[1] During the 1980s, fluoridated dentifrice formulations became well established.[7]

In the present era, there is overwhelming evidence that fluoride dentifrice is highly effective in preventing caries.[1] As well as Concerns have been raised regarding the role of fluoride dentifrice in dental fluorosis. [9]

'Dentifrices' include toothpastes, gels, powders and chewable tablets, designed to be used primarily as adjuncts to mechanical cleaning i.e. toothbrushing. [11]

Dentifrices-General Concept

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1. Classification of Dentifrices based on purpose of use Cosmetic Dentifrices
2. Therapeutic Dentifrices

Cosmetic Dentifrices The use of words such as 'protects', 'cleans', 'freshens breath', 'fights bacteria which may cause gum problems', 'whitens' or 'fights tartar' are considered to be cosmetic claims. [12]

Therapeutic agent: These are active components added to the dentifrice to reduce caries, inhibit tartar formation, help in desensitization and have an antimicrobial and anti-inflammatory action. Eg: Fluoride, triclosan, strontium chloride etc .[10]

Components of Dentifrices

Dentifrices are generally formulated to contain cleansing agents in the form of abrasives, surfactants, binding and thickening agents and rheology modifiers, humectants, preservatives, and additives to improve sensorial experience such as colouring and flavouring agents.

In addition, many dentifrices contain active ingredients designed to prevent oral disease such as caries and periodontal disease. [10]

Classification of tooth pastes based on certain characteristics of the active ingredients.

1. For caries prevention and treatment
2. For periodontal disease prevention and treatment
3. For treatment of sensitive teeth
4. Whitening and bleaching toothpastes
5. Bleaching toothpastes[10]

Toothpastes with a specific purpose

Anticaries agents in toothpastes -Fluoride (F)

Systematic reviews have concluded that fluoride toothpastes are effective in reducing caries. Fluoride toothpastes reduce caries in the deciduous dentition by 37% and by 24% in the permanent dentition of children and adolescents. The effectiveness of fluoride toothpastes are concentration dependent. Brushing with a fluoride toothpaste should be recommended twice daily, whilst rinsing with large volumes of water should be discouraged.

Various forms of fluoride, such as amine fluoride, stannous fluoride, sodium fluoride and sodium monofluorophosphate, have been used in toothpaste formulations. The relative effectiveness of these different fluoride salts has been the topic of much debate but a systematic review concluded that they were equally effective. Dentifrices containing fluorides in concentrations >1500ppm are classed as prescription only medicines (POM) and should be used only above the age of 10 years and for the management of high caries risk individuals such as those with xerostomia or root surface caries.[10]

In 2019, in response to global concerns related to the triclosan ingredient, the product was reformulated and now contains SnF2 as the anticaries agent, in addition to stain mitigation technology to help reduce the potential for tooth staining.[6]

Fluoride Compounds Used in Dentifrices

Twice-daily brushing significantly lowers the risk of dental caries, with studies indicating a 14% reduction in incidence. For effective plaque removal and prevention of excess fluoride ingestion, brushing in children under four years of age should always be supervised.

For children at high risk of caries, higher concentrations—ranging from 1,350 ppm to 1,500 ppm—are recommended, especially from the age of seven and beyond. However, due to the immature swallowing reflex in children under six, toothpaste with 1,500 ppm fluoride is not recommended for this age group to avoid the risk of dental fluorosis. Children under three should use a smear or rice-sized amount of toothpaste. From age three to six, a peasized amount is appropriate.[14]

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Standard formulations for adults typically contain fluoride concentrations ranging from 1000 to 1500 ppm, delivered through compounds such as sodium fluoride (NaF), stannous fluoride (SnF2), or sodium monofluorophosphate (MFP).[13]

Three compounds have been used widely as delivery substances, namely sodium fluoride, sodium monofluorophosphate and stannous fluoride.[2]

Sodium fluoride (NaF): Sodium fluoride toothpaste with 2,800 ppm concentration can be prescribed starting at age 10, while the 5,000 ppm version is appropriate from age 16. [14]

Eg- Sensodyne Repair & Protect — contains sodium fluoride (~1450 ppm F)

Sodium monofluorophosphate (MFP): Three compounds have been used widely as delivery substances, namely, sodium fluoride, sodium monofluorophosphate and stannous fluoride.[2]

MFP requires enzymatic hydrolysis and thus releases fluoride more slowly.[5]

Eg-Colgate Strong Teeth.

Stannous fluoride (SnF2): Stannous itself has antibacterial properties, and fluoride has anticavity properties.[13]

Stannous fluoride not only provides fluoride ions but also exerts antimicrobial activity through tin, offering broader protective effects.[5]

Amine fluorides: Amine fluoride acts more rapidly due to its surfactant properties and strong enamel adhesion, synergistic benefits have been observed when AmF is combined with SnF2, resulting in enhanced antibacterial and anti-demineralization properties .[5]

Eg- Elmex Anti-Caries Toothpaste — contains amine fluoride (olaflur)

Novel fluoride compounds

High fluoride concentration compounds, e.g., AgF, Ag (NH3)2F, to arrest more advanced carious lesions with and without prior removal of carious tissue are being used in several countries as part of the Atraumatic Restorative Treatment (ART) approach.[1]

Silver diamine fluoride shows promise for high-risk populations[14]. SDF is a topical agent used for arresting active carious lesions and offers a non-invasive alternative for caries management, particularly in populations with limited access to restorative care .[5]

Overview of fluoride toothpaste [5]

Product Type	Toothpaste
Fluoride Concentration	500–1500 ppm (standard); up to 5000 ppm in prescription formulations
Mechanism of Action	Topical remineralization, antibacterial effects
Primary Indications	Daily home use; high-fluoride pastes for adults at elevated caries risk
Limitations	Risk of ingestion in young children; esthetic concern not relevant
Cost/ Accessibility	Affordable and widely available in high-income settings, but significantly less affordable in low-income countries

Mechanism of Action

An acid attack of the mineral phase results in the development of a distinct cavity in the tooth. The loss of tooth structure in this way can be reversed in the process of remineralisation.

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Figure 1:

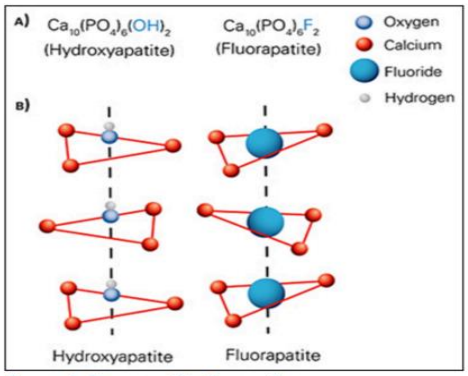


Figure 1. Fluorapatite Formation.
(A) Fluoride ions (F^-) replace hydroxyl ions (OH^-) in hydroxyapatite to form fluorapatite in the tooth enamel.
(B) A portion of the apatite crystal lattice is depicted showing the replacement of hydroxide for fluoride.
Adapted from: Posner, 1985.[24]

Fluoride ions assist in combating the development of dental caries. It appears to do so by three mechanisms, as follows:

1. Formation of fluorapatite mineral. The fluorapatite mineral is less soluble than the carbonate apatite, and this reduces the rate of dissolution in the early stages of demineralisation
2. Shifting the demineralisation–remineralisation steady state to favour the remineralisation processes .
3. Reducing the ability of saliva to solvate calcium and phosphate ions by forming strong hydrogen bonds with water molecules. This causes calcium and phosphate to be less soluble in the saliva, thereby promoting remineralisation [2]

Figure 2:

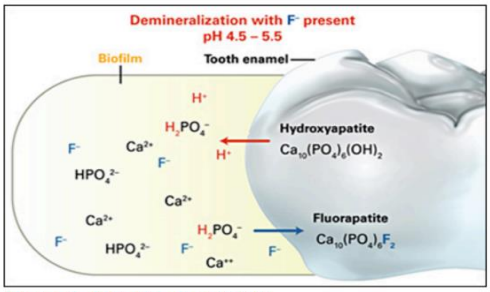


Figure 2. Fluoride Reactivity.
Under cariogenic conditions, carbohydrates are converted to acids by bacteria in the plaque biofilm. When the pH drops below 5.5, the biofilm fluid becomes undersaturated with phosphate ion and enamel dissolves to restore balance. When fluoride (F^-) is present, fluorapatite is incorporated into demineralized enamel and subsequent demineralization is inhibited.
Adapted from: Cury, 2009.[31]

Demineralization occurs when there is an imbalance between processes of mineral gain and loss. Fluoride may interact with these processes in several ways. It is now widely accepted that fluoride has both systemic and topical modes of action.

The interaction of fluoride with the mineral component of teeth produces a fluorohydroxyapatite (FHAP or FAP) mineral, by substitution of OH– with F–. This results in increased hydrogen bonding, a more dense crystal lattice, and an overall decrease in solubility.

The concentration of fluoride at the crystal surfaces and the fluoride concentration in the liquid phase during a cariogenic challenge are important. As little as 0.5 mg/L fluoride in acidic solutions causes a reduction in the dissolution rate of apatite.

The carious lesion occurs when the demineralization process outweighs the remineralization process, and net damage occurs. When fluoride is also present, formation of fluorohydroxyapatite (FHAP or FAP) results in a mineral with an even greater level of acid resistance.

The use of low concentration fluoride products, such as dentifrices on a daily basis, will help maintain this favorable saturation. Thus, remineralization of the lesion may result.

Fluoride, at a relatively low concentration, may also interact with the oral bacteria to reduce plaque acid production. One is the well-known interaction of fluoride with the enzyme enolase which could directly reduce the production of bacterial acids. There is also an indirect effect on the phosphotransferase system (PTS) pathway that decreases the amount of sugar entering the cell by limiting phosphoenolpyruvate (PEP).

It is also likely that diffusion of fluoride into the cell occurs as hydrofluoric acid (HF) which then dissociates, lowering the intercellular pH and disrupting the cell. Fluoride may affect the ability of the cell to remove

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excess H+ and less acid production may result from cytoplasmic acidification.

The overall effect is less acid and a less acidic environment that should reduce the driving force for dissolution. Importantly, some forms of fluoride may be better than others with respect to effects on oral bacteria. For example, stannous fluoride (SnF2) provides antibacterial effects that are not delivered by other fluoride actives used in dentifrice formulations.[6]

Biological role and importance in odontogenesis

Fluoride influences odontogenesis through several biological mechanisms, both direct and indirect, such as: incorporation into the mineral structure, alteration of crystal morphology, regulation of gene expression, and modulation of ion transport.

Molecular studies have shown that fluoride modulates the expression of key genes involved in amelogenesis, including:

AMELX—encodes amelogenin, the main protein of the enamel matrix; ENAM—encodes enamelin, involved in initiating crystal nucleation; MMP-20 (matrix metalloproteinase-20) and KLK-4 (kallikrein-related peptidase 4)—proteases responsible for the controlled degradation of the organic matrix. Through these effects, fluoride contributes to the coordination of mineralization and protein resorption processes during enamel development. Fluoride also modulates ameloblast function by influencing ion channels and membrane pumps (e.g., Ca2+-ATPases, bicarbonate, and anion channels), thereby regulating local pH and creating favorable conditions for crystal growth. An adequate fluoride intake during active odontogenesis is essential for development of a caries-resistant dentition. The recommended daily dose for children is 0.05–0.07 mg fluoride/kg body weight/day, with sources including fluoridated drinking water, food, supplements, and unintentional ingestion from toothpaste. However, excessive and sustained exposure to fluoride—typically above 0.1 mg/ kg/day—can lead to dental fluorosis, a mineralization disorder caused by ameloblast dysfunction during the maturation phase. Clinically, fluorosis is characterized by opaque white spots, horizontal white lines, or, in severe cases, pitting and surface defects. Once the teeth have erupted and the enamel is fully mineralized, systemic fluoride overexposure can no longer cause fluorosis. Fluorosis severity is not only directly proportional to the level and duration of fluoride exposure but is also influenced by individual variations in absorption, metabolism, and excretion. The intensity of fluorosis correlates closely with plasma fluoride concentration, which is in equilibrium with tissue fluid surrounding the developing enamel organ. Plasma concentration depends on multiple factors, including total fluoride intake, route of administration (oral or inhaled), renal function, bone metabolism dynamics, and overall metabolic activity. It is important to note that not all children exposed to the same fluoride levels develop fluorosis to the same degree.

This reflects interindividual differences related to: Total fluoride intake (including processed foods, supplements, or accidental toothpaste ingestion); Duration and timing of exposure (especially between 15 and 30 months of age for permanent upper incisors); Genetic susceptibility of ameloblasts to fluoride-induced metabolic stress; Nutritional status (intake of calcium, phosphorus, vitamin D, etc., can modulate fluoride's effect on enamel). Cumulative exposure from multiple sources—including supplements, tablets, or mouth rinses—can also significantly increase risk.[15]

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Fluoride fixation in hard tissues: Teeth and bones

Regarding dentition, fluoride fixation is directly correlated with the developmental stages of dental hard tissues. Fluoride is incorporated primarily into the enamel and dentin, and to a lesser extent, into the cementum. The fixation process follows three distinct physiological stages:

1. During amelogenesis and dentinogenesis: Fluoride is delivered to the mineralizing dental matrix via the bloodstream and peridental interstitial fluid.
2. During the pre-eruptive period: After the crown has completed mineralization, fluoride absorption is limited but still possible through the diffusion of ions from pericoronal fluids.
3. After eruption: Fluoride fixation into the dental structure becomes exclusively superficial and dependent on topical exposure. At this stage, remineralization is local and does not affect the entire volume of enamel. [15]

Mechanisms of action of fluoride in caries prevention

The prophylaxis of dental caries through fluoride use is based on three essential topical mechanisms:

1. Inhibition of enamel demineralization-. Fluorapatite ($Ca_5(PO_4)_3F$), formed by substituting the OH^- group in hydroxyapatite ($Ca_5(PO_4)_3OH$) with F^-, is significantly more resistant to acid dissolution than calcium hydroxyapatite
2. Stimulation of remineralization processes- During the natural remineralization process, bacterial acids are neutralized by the buffering action of saliva, allowing the re-precipitation of minerals (calcium and phosphate ions) into the enamel structure. These minerals are present in saliva in a supersaturated state, which promotes the regeneration of apatite crystals.
3. Antibacterial action on the dental biofilm (dental plaque)- Fluoride also has antimicrobial properties, especially under low pH conditions. In such environments, fluoride ions (F^-) penetrate bacterial cell walls in the form of hydrofluoric acid (HF). Once inside the cell, HF dissociates into F^- and H^+, acidifying the bacterial cytoplasm and inhibiting key metabolic enzymes such as enolase, thereby disrupting glycolysis and reducing acid production.

Additionally, fluoride:

- Inhibits phosphoenolpyruvate phosphotransferase, an enzyme involved in carbohydrate fermentation, reducing lactic acid production;
- Interferes with glucose transport into bacterial cells and inhibits the synthesis of extracellular polysaccharides that form the plaque matrix, reducing Streptococcus mutans adhesion to enamel surface; and
- Disrupts microbial adherence to tooth surfaces by interfering with salivary proteins and glycoproteins, hindering plaque formation.

The antimicrobial effect of fluoride is cumulative, increasing over time with repeated exposures to fluoride. Importantly, fluoride ions present in saliva, the gingival sulcus, and topical products are retained in the dental biofilm, where they form a localized, slow-release reservoir. This fluoridated microenvironment provides continuous protection at the enamel surface and facilitates remineralization of early carious lesions. [15]

Fluoride and post-eruptive enamel maturation

After eruption, enamel is not fully mineralized and remains vulnerable to acid attack. Continuous fluoride exposure during this critical post-eruptive phase contributes to enamel maturation by strengthening the crystal structure and increasing resistance to demineralization. Topical fluoride can be incorporated

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into the superficial enamel layer as fluorapatite, offering substantial protection against future acid challenges.

This mechanism relies on maintaining a constant concentration of fluoride in both saliva and the dental biofilm, which contributes to a dynamic balance between demineralization and remineralization processes.

Calcium fluoride is unstable and gradually dissolves in contact with saliva, releasing bioavailable fluoride. In addition to these primary mechanisms, fluoride also has several indirect effects, particularly during the formation of dental hard structures:

- It increases the growth rate of crystals, making them larger, more regular, and less soluble.
- It reduces occlusal relief and tooth dimensions, aspects that contribute favorably to a lower incidence of cavities.
- It normalizes protein and mineral metabolism when administered enterally.
- It has an optimal cariostatic effect at daily doses of 2 mg, beyond which the benefit does not increase proportionally.[15]

Effect on Enamel Remineralization by Fluoride Dentifrices

The primary preventive action of fluoride is localized, enhancing the remineralization of enamel and inhibiting the demineralization process. In the natural remineralization process, the pH of the oral cavity is restored by salivary buffering, halting further enamel dissolution. Saliva, being supersaturated with calcium and phosphate, contributes these minerals back to the enamel surface. The presence of partially demineralized enamel crystals provides nucleation points for mineral redeposition.

Fluoride enhances this process by integrating into these subsurface crystals and facilitating the precipitation of new mineral layers .[14]

Action on Plaque and Salivary Fluoride Reservoir- Calcium fluoride appears to be a critical step in understanding key features of the action of topically administered fluoride. Contrary to popular belief, calcium fluoride acts as a fluoride reservoir rather than a permanent reaction product [16].

Fluoride retained in plaque and saliva maintains a constant low level of fluoride in the oral environment [1]. This low level of fluoride in saliva and plaque fluid plays a significant role in inhibiting demineralization and enhancing remineralization [14].

Classification Of Fluoride Dentifrices

Classification Based on Fluoride Concentration

Fluoride dentifrices are classified based on the concentration of fluoride present in the formulation. [1]

- **Low fluoride dentifrices (<500 ppm)-**Toothpaste with low fluoride concentrations (250, 500 and 550 ppm) have been marketed to reduce fluoride ingestion by young children in order to minimize the risk of dental fluorosis. [6]

One way of reducing the amount of fluoride ingested is to reduce the level of fluoride in toothpaste to either 500 or 250 ppm. [6]

Table 2. Summary of Trials of Low-fluoride Dentifrices

Author	Year	Age[a]	Water[b]	Duration	Fluoride Concentration	N	Caries Increment	% Difference[c]	Statistically Significant Difference
Reed[39]	1973	6-14	Non-F	2 years	1000ppm NaF	362	3.20[d] (0.20)[e]	——	Yes[f]
					500ppm NaF	387	3.66 (0.22)	14.4	No
					250ppm NaF	379	3.70 (0.23)	15.6	No
					Placebo	397	4.00 (0.21)	25.0	——
Gerdin[40]	1974	3.5 (mean)	Non-F	2 years	1000ppm NaF	105	4.23[d] (3.53)[h]	——	No[f]
					250ppmKF-Mn	108	3.83 (3.21)	-9.0	
Forsman[41]	1974	10-11	Non-F	2 years	1000ppm MFP	137	3.03[d]	——	No[f]
					250ppm MFP	140	2.91	-4.0	No
					250ppm NaF	137	2.82	-6.9	No
					Placebo	145	3.25	7.3	——
		10-12	Non-F	2 years	1000ppm MFP	132	5.31[d]	——	No[f]
					250ppm MFP	130	5.17	-2.6	No
					Placebo	132	5.68	7.0	——
Koch et al.[42]	1982	12-13	NR	3 years	1000ppm MFP		5.8[d] (0.55)[e]	——	No[f]
					1000ppm NaF	514	6.1 (0.51)	5.1	No
					250ppm NaF		6.3 (0.46)	8.6	
Mitropoulos et al.[43]	1984	12-13	Non-F	32 mo.	1000ppm MFP	360	3.6[d] (3.93)[h]	——	Yes[f]
					250ppm MFP	365	4.29 (4.99)	18.8	
Winter et al.[24]1989		2	NR	3 years	1055ppm MFP	1073	2.29[g]	——	No[f]
					550ppm NaF + MFP	1104	2.52	10.0	
Koch et al.[44]	1990	11-12	Non-F	3 years	970ppm NaF	209	10.1 (8.1)	——	Yes[f]
					250ppm NaF	203	12.7[d] (9.3)[h]	-20.5	

a=Age at baseline; b=Community water fluoride status; c=Compared with 1000 ppm as standard; d=DMFS; e=(Standard error of the mean); f=ANOVA; g=dmfs; h=(Standard deviation); i=Compared vs. other active dentifrice; j=Compared vs. placebo; NR=Not Reported

- **Standard fluoride dentifrices (1000–1100 ppm)**

Systematic reviews and meta-analyses have confirmed the benefit of 1000–1500 ppm F-containing toothpaste to achieve caries prevention. It is standard formulations for adults typically [18]

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- **High fluoride dentifrices (>1450 ppm)**

Fluoride concentration 2500–5000 ppm is recommended for individuals with high caries risk. [17]

Dentifrices for caries prevention and treatment: In general, use of toothpastes with a fluoride concentration of not less than 1000 ppm is recommended. In addition, it is proven that toothpastes with fluoride concentrations of 400-550 ppm do not differ from placebo toothpastes. According to the latest research data, children from 2-3 years of age swallow 48% of toothpaste, but children from 6-7 years of age swallow 25% of toothpaste. In order to reduce the risk of fluorosis in the most susceptible group (4-6 years of age) it is recommended that they ingest no more than 0.1 mg (it is safer, if it is not more than 0.05 mg) F per 1 kg body mass per day. Strong spices and irritants can increase the secretion of saliva which causes a salivary protective reaction. Irritants include such substances as sodium lauryl-sulfate, which is the most common foaming substance added to toothpastes. [17]

Fluoride Dentifrices In Pediatric Dentistry

Fluoride therapy has been the first step in arresting early lesions. [21]

Parents must be strongly advised to apply an age-related amount of toothpaste and assist or supervise tooth brushing until at least 7 years of age. [22]

Initiating toothbrushing with fluoride dentifrice prior to age two was significantly associated with dental fluorosis. [9]

Children aged less than six years may swallow an estimated 0.3 g of toothpaste per brushing.

A child-sized toothbrush covered with a full strip of toothpaste holds approximately 0.75 to 1.0 g of toothpaste.

It is generally recommended that no more than a pea-sized amount of toothpaste should be used for children under six years of age. [23]

Only 27% of children dispensed the correct amount of dentifrice for this age group, i.e., a pea-head size. [20]

Supervised brushing has been shown to increase the caries-preventive effect of fluoride toothpaste. [23]

Fluoride therapy eliminates the need for cavity preparation and utilization of air motors.[21]



Efficacy Of Fluoride Dentifrices

The inherent properties of a fluoride dentifrice product, biological and behavioral factors can modify its anticaries effectiveness. All of these factors interplay in what can be described as the "application" phase (the initial interaction of relatively high concentrations of fluoride with the tooth surface and plaque), and the "retention" phase (the fluoride remaining in the mouth after brushing that is retained in saliva, plaque and plaque fluid, the tooth surface, and oral soft tissue reservoirs). Behavioral factors include the frequency of dentifrice use, length of brushing, rinsing practices after brushing, the time of day that dentifrice is applied, and amount of dentifrice applied to the brush.[24]

The pathogenesis of dental caries involves a multifactorial interaction over time between acidogenic bacteria, fermentable carbohydrates, and host-related variables such as saliva composition and oral hygiene practices. [14]

One of the earliest studies of low-fluoride dentifrices found higher DMFS increment (which included

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radiographic examination) for reduced fluoride dentifrices over a two-year period when compared to 1000 ppm F dentifrice.

Mitropoulos et al reported that 250 ppm MFP dentifrice was significantly less effective (19%) than a 1,000 ppm MFP dentifrice in a 32-month trial in children aged 12-13 years.

A 1990 study of the anti-caries effectiveness of 250 ppm and 1000 ppm NaF dentifrices in Iceland also found that the lower fluoride dentifrice was significantly less effective (21%) in preventing caries in children between the ages of 11-12 years.[9]

Reported efficacy of fluoride intervention in preventing or arresting dental caries.

Product Type	Fluoride Concentration	Mechanism of Action	Primary Indications	Limitations	Cost/ Accessibility
Toothpaste	500–1500 ppm (standard); up to 5000 ppm in prescription formulations	Topical remineralization, antibacterial effects	Daily home use; high-fluoride pastes for adults at elevated caries risk	Risk of ingestion in young children; esthetic concern not relevant	Affordable and widely available in high-income settings, but significantly less affordable in low-income countries
Fluoride varnish	~22,600 ppm fluoride ions	Sustained topical release, promotes remineralization	Professional application for high-risk individuals	Potential taste issues, cost	Moderate to high cost; requires professional delivery; insurance coverage (e.g., Medicaid/ACA coverage) influences accessibility in certain settings

5

Effect of Fluoride Concentration on Efficacy- Remineralization was significantly greater in the 500 ppm fluoride group than the 250 ppm fluoride group. Higher fluoride concentrations did not result in greater remineralization beyond certain levels.[19]

Toothpastes with higher fluoride concentration demonstrated increased preventive effect compared with standard dentifrices. The caries preventive effect of fluoride-containing toothpaste has shown strong evidence when used daily compared to placebo. [25]

Influence of Fluoride Formulation and Brushing Practices on Efficacy

Clinical trials suggested the superiority of sodium fluoride composition over stannous fluoride and sodium monofluorophosphate favouring sodium fluoride containing toothpaste.

Others suggested that amine fluoride toothpaste resulted in higher salivary fluoride concentrations and therefore marked remineralization of caries compared to sodium fluoride and sodium monofluorophosphate containing toothpastes.

Post-brushing rinsing was found to result in significantly lower salivary fluoride concentrations compared to non-rinsing groups.

Higher salivary fluoride retention enhances the anti-caries effectiveness of fluoride dentifrices.[18]

Toothpastes containing up to 5000 ppm F are primarily intended for patients with special care needs, adolescents with increased caries risk and those under treatment with fixed orthodontic appliances. Conclusive evidence for their superior effectiveness is, however, lacking .[22]

Caries preventive effect of fluoride toothpaste-

Intervention	Control	PF % (95% CI)
Fluoride toothpaste	Placebo	24 (21–28)
Supervised brushing	Non-supervised	11 (4–18)
Brushing twice per day	Once per day	14 (6–22)
1450–1500 ppm F	1000–1100 ppm F	8 (1–16)
Fluoride toothpaste + other sources*	Fluoride toothpaste	10 (2–17)

PF is prevented fraction, expressed as percentage, with confidence intervals (Marinho 2009)

Safety And Toxicity of Fluoride Dentifrices

Fluoride Metabolism and Biological Basis of Toxicity

Once absorbed, F travels throughout the body via the blood circulation before being filtered by the kidney and excreted in urine, which thus ensures the majority of F removal from the body.

Approximately 60% of ingested F by healthy adults are excreted in the urine, but only 45% for children, with the rest re-circulating into the plasma or deposited into the bone.[3]

Dental Fluorosis and Chronic Toxicity

Dental fluorosis is a developmental disturbance of enamel which occurs during enamel forming and is

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caused by systemic overexposure to fluoride during the first six years of life.

The enamel contains more protein, is porous, opaque and less transparent.

Clinical manifestation vary from narrow white horizontally running lines to larger patches or yellow to light brown colored areas of porous enamel, to loss of enamel in varying degrees. [28]

Although the amount of fluoride ingested beyond which fluorosis may occur is not known accurately, a threshold of 0.05 to 0.07 mgF/kg body weight has been suggested.[23]

Acute Fluoride Toxicity and Safety Limits: Acute toxicity can occur after ingesting one or more doses of fluoride over a short time period which then leads to poisoning.

The stomach is the first organ that is affected and first signs and symptoms are nausea, abdominal pain, bloody vomiting and diarrhea.

This is followed by collapse with paleness, weakness, shallow breathing, weak heart sounds, wet cold skin, cyanosis, dilated pupils, hypocalcaemia and hyperkalemia, and in two to four hours even death.

The probable toxic dose (PTD) was defined at 5 mg/kg of body mass and represents the minimal dose that could trigger serious and life-threatening signs and symptoms. [28]

Sodium lauryl sulfate: Sodium lauryl sulphate (SLS) is a detergent commonly used in toothpastes and may occasionally cause mucosal desquamation or ulceration

Triclosan: In 2005, a "toothpaste cancer alert" appeared in some newspapers after a report that triclosan can react with water to produce chloroform which, if inhaled in large enough quantities, can cause depression, liver problems and, in some cases, cancer. However, other studies suggest that triclosan may have chemotherapeutic potential against cancer.

Soft tissue reactions: Soft tissue reactions may arise, most often to essential oils, flavourings, cinnamonaldehyde, benzoates, or carvone, and manifest as direct irritants or allergic reactions in the mouth, lips as contact cheilitis. Rarely allergic rhinitis or asthma may occur. Essential oils, such as peppermint, anethole, cinnamon, cloves and spearmint and antimicrobial agents can cause cheilitis or circumoral dermatitis. Carvone is a common constituent of essential oils and may be implicated. [12]

Safety Recommendations and Preventive Guidelines

Using no more than a smear or rice-sized amount of fluoridated toothpaste for children less than 3 years of age may decrease risk of fluorosis.

Using no more than a pea-sized amount of fluoridated toothpaste is appropriate for children 3 to 6 years of age.[29,30]

Preventive programmes should be re-evaluated at regular intervals and adapted to a patient's or population's needs and risks.[22]

The total fluoride intake for the youngest members of the population can often be higher than optimal which may lead to an increased incidence of very mild and mild fluorosis.[26]

Recommended dietary allowance

The adequate daily intake of fluoride for males is 4mg and females is 3mg. Various studies have indicated that children less than 6 years of age swallow 24% to 60% of dentifrices, which is almost completely absorbed. All dentifrices contain 1000 or 15000 ppm fluoride as sodium fluoride or mono fluoro phosphate. If an 18kg 5-year old child applies 0.5g of dentifrices to the toothbrush and ingests 44%, fluoride ingestion will be 12 micrograms/kg. If the child brushes his teeth twice daily;

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ingestion will be 24 microgram/kg /day.[1] The ADA proposed a modification to their recommendations for the amount of fluoride in drinking water to be 0.7 µg/ml (ppm) at all places in the United States.[32]

Dosage of fluorine in dental products and its probable lethal dose.[1]:

Dosage of fluorine used in dental products and probable lethal dose			Concentration of fluoride		Amount of product and F usually used		Amount containing the ptd	
Vehicle	Compound	Amount	%	PPM	Product	Fluoride	10 Kg Child	20 Kg Child
Rinse	NaF	0.05	0.023	230	10ml	2.3mg	215ml	430ml
	NaF	0.20	0.091	910	10ml	9.1mg	55ml	110ml
	SnF_2	0.40	0.097	970	10ml	9.7mg	50ml	100ml
Dentifrice	NaF	0.22	0.10	1000	1g	1.0mg	50g	100g
	MFP	0.76	0.10	1000	1g	1.0mg	50g	100g
	MFP	1.14	0.15	1500	1g	1.0mg	33g	66g
Topical Gel Or Solution	NaF (APF)	2.72	1.23	12300	5ml	61.5mg	4ml	8ml
	SnF_2	0.40	0.097	970	1ml	0.97mg	50ml	100ml
	SnF_2	8.0	1.94	19400	1ml	19.4mg	2.5ml	5ml
Tablet	0.25mg F	_	_	_	1/day	0.25mg	200 mg	400 Mg
	0.50mgF	_	_	_	1/day	0.50mg	100 Mg	200 Mg

Public Health and Regulatory Considerations

The U.S. FDA regulates that the total amount of fluoride in any package sold over-the-counter should not exceed a specified amount to prevent problems if the whole tube is swallowed.

ISO11609 limits the maximum fluoride content for a single size container to reduce risk associated with ingestion. [27]

Guidelines And Recommendations For Fluoride Dentifrices

The 2019 Guidelines on fluoridated toothpaste

- From the time that teeth first erupt (about six months of age) to the age of 17 months, children's teeth should be cleaned by a responsible adult, but not with toothpaste.
- For children aged from 18 months to five years (inclusive), the teeth should be cleaned twice a day with toothpaste containing 0.5–0.55 mg/g fluoride (500–550 ppm). Standard toothpaste is not recommended for children under 6 years of age unless on the advice of a dental professional or a trained health professional.
- For people aged 6 years or more, the teeth should be cleaned twice a day or more frequently with standard fluoride toothpaste containing 1–1.5 mg/g fluoride (1000–1500 ppm). People aged 6 years or more should spit out, not swallow, and not rinse. [31]

Summary of Fluoride Based Preventive Measure by Age Group and Risk Level

Preventive Method	Recommended Age Group	Fluoride Concentration	Frequency of Use	Indication	Notes
Fluoride Toothpaste	6 months to 3 years	1000 ppm	Twice daily	All children	Use smear size ; supervise brushing to prevent swallowing
Fluoride Toothpaste	3 to 6 years	1000-1100 ppm	Twice daily	All children	Use pea sized amount; avoid high fluoride toothpaste
Fluoride Toothpaste	7+ years ; High - Risk	1350-1500 ppm	Twice daily	High caries risk	Standard recommendation for older children and adults
Prescription Toothpaste	10+ years/ 16+ years	2800-5000 ppm	Twice daily	High caries risk	Short term or chronic use based on need

27

Brushing behaviour is also important: Brushing twice a day is linked to a 20% to 30% lower likelihood of caries compared to brushing once or less daily. It should be noted that brushing frequency is linked to socioeconomic status, with children in poorer families brushing less, and this being one reason they experience more caries.[28]

Dietary fluoride supplementation schedule-

Table. DIETARY FLUORIDE SUPPLEMENTATION SCHEDULE

Age	<0.3 ppm F	0.3 to 0.6 ppm F	>0.6 ppm F
Birth to 6 months	0	0	0
6 months to 3 years	0.25 mg	0	0
3 to 6 years	0.50 mg	0.25 mg	0
6 to at least 16 years	1.00 mg	0.50 mg	0

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Advances in Toothpaste Formulation and Functional Dentifrices

Advances in Toothpaste Formulation and Functional Dentifrices-

The research work aims to develop functional toothpastes with combined enamel remineralization and antibacterial effects using nano-hydroxyapatites (nHAPs) and birch extract. The outcomes highlighted enamel morphology improvements due to the toothpaste treatment also having various efficacious antibacterial effects. [33]

Nanotechnology in Fluoride Dentifrices Nanotechnology might be critical in preventing dental disease through improved mouthwash and toothpaste. The relatively new ability to synthesize pure 'free' NPs enables the development of new performance systems featuring novel physicochemical and bifunctional features, as well as nontoxicity. [34]

Nano-Hydroxyapatite and Remineralization Advances: Micro- and Nano-HAP are similar to natural enamel HAP structures. It has been demonstrated that HAP adheres to the enamel surface and penetrates the pore and crack to restore the surface integrity of the enamel. HAP particles have a more remarkable ability to penetrate the lesion than fluorides, which can only remineralize the surface. It has been determined that calcium and phosphate ion availability are two main factors restricting remineralization. Studies demonstrated that teeth treated with HAP toothpaste had considerably greater calcium contents than untreated ones. Nano-HAP has shown positive results in people suffering from dentin hypersensitivity. It is noticeable that HAP has a remineralization effect that increases the broad range of its capabilities, especially in children's dental care products. [34]

Nano-calcium fluoride, which reduces caries and increases labile fluoride concentration, silver nanoparticles (AgNPs) with antimicrobial and anti-inflammatory properties, and nano-hydroxyapatite (n-HAP) containing different metal ions are among the inorganic compounds used in toothpaste formulation. Nanomaterials, which are attractive due to their biocompatibility, are among the most common matrix materials. Research investigations into the effectiveness of nano-hydroxyapatite (nHAP) crystals within toothpaste formulations have revealed notable enhancements in the microhardness properties of human enamel following the application of toothpaste containing nHAPs. Additionally, there is evidence of the proficient occlusion of dentinal tubules by nHAP particles, which adhere to the tooth surface and impede mineral dissolution processes. [33]

Calcium Phosphate Systems and Fluoride Optimization Calcium phosphate materials have been shown to accelerate remineralization processes. Since sodium trimetaphosphate plays a significant role in slowing down the dissolution of HAP, it has been used as an additive in toothpaste formulations. It has been demonstrated that the addition of TMP to toothpaste containing 500 ppm F has effects comparable to those of commercial toothpaste containing 1100 ppm F in terms of enamel demineralization. [34]

Novel Fluoride–Nanoparticle Systems and Remineralization Approaches -Nanoscience has gained a lot of attention in recent years in the field of dental research. By combining fluoride ions and silver nanoparticles, a very effective formula has been created, which has both antibacterial and remineralization properties; therefore, it could be used for arresting white spot lesions in primary teeth. Additionally, due to the nanostructure, no tooth staining has been caused. NSF is

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a relatively new development and alternative to the previously known silver compounds, possessing remineralizing properties without staining the teeth black.[35]

Controlled Fluoride Release Systems

The hydroxyapatite-Eudragit RS100 fluoride system presents a cutting-edge method in controlled fluoride release, aimed at enhancing dental health through improved remineralization and caries prevention. Hydroxyapatite (HA), a calcium phosphate mineral that is a primary component of tooth enamel, serves as a biocompatible carrier in this system. Eudragit RS100, a polymethacrylate polymer commonly used in drug delivery due to its ability to provide a controlled release profile, is combined with hydroxyapatite to create a composite that allows for sustained fluoride ion release over time. The slow and continuous release of fluoride ions from this composite helps maintain fluoride availability on the enamel surface, simulating the natural remineralization process and potentially reducing caries progression by enhancing enamel resistance to acid attacks. Furthermore, the controlled-release aspect reduces the need for repeated fluoride applications, potentially improving compliance and accessibility, especially for individuals in areas with limited dental care resources.[36]

Smart Fluoride Delivery and Personalized Preventive Dentistry

Nano-sized fluoride carriers can penetrate enamel microstructures more effectively than conventional methods, providing targeted fluoride delivery where it is most needed. Biomimetic materials, designed to mimic natural tooth structures, hold promise for improved fluoride integration and retention in enamel. A particularly promising development is the emergence of "smart" fluoride delivery devices. These devices can respond dynamically to changes in the oral environment, such as shifts in pH, temperature, or salivary composition.[33]

A promising development in restorative materials is the introduction of nanocomposites, which aim to combine the beneficial fluoride release profile of GICs with the favorable physical characteristics of composite resins. Recent studies suggest that certain nanocomposite formulations can achieve fluoride release levels comparable to those of GICs and RMGIs, while maintaining superior durability and esthetics. Studies show that acidic conditions significantly increase the release through increased dissolution of fluoride-containing components, which is strategically important because of carious bacteria that produce acids that lower the local pH, triggering the ‘on-demand’ release of fluoride when it is most needed. The fact that fluorinated materials may have recharging ability has not escaped the attention of some researchers. Mitwalli et al. determined that CaF2 nanocomposites with a relevant resin matrix composition have the potential to recharge and release F- ions and Ca- ions over a long period of time.[37]

Preventive Fluoride Modalities and Silver Diamine Fluoride Approaches:

Topical fluorides come in multiple forms, commonly as sodium fluoride varnish (NaF) and gel, which is primarily classified as an agent to manage dentinal hypersensitivity but also used as a caries preventive agent. However, it is not capable of arresting it, which withdraws attention to new approaches that have the potential to prevent and arrest dental caries, such as silver diamine fluoride. Silver diamine fluoride (SDF) stands out in this new approach due to its acclaimed ability to halt the progression of existing carious lesions and prevent the emergence of new ones.[38]

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Emerging Biomimetic Materials and Combination Remineralization Systems:

Although fluoride-based products remain the conventional standard for caries prevention, their limitations in subsurface remineralization have prompted the exploration of alternative strategies. Combined nanoHAP and fluoride use showed reduced demineralization. These findings suggest that nanoHAP serum may serve as an adjunctive pretreatment for enhancing enamel resistance against demineralization.[39]

Despite these encouraging findings, there is still a lack of well-designed clinical trials specifically evaluating green-synthesized NSF, which limits the ability to translate current in vitro findings to clinical settings. Additionally, other compounds such as casein phosphopeptide-amorphous calcium phosphate and biomimetic hydroxyapatite showed promising results, so their supplementation in combination with NSF could be explored in future studies to enhance therapeutic outcomes. New insight into the effectiveness of green-synthesized NSF, which also offers the added advantage of being sustainable and eco-friendly. Moreover, research has focused on innovative delivery systems, such as sustained-release varnishes and polymeric carriers designed to prolong fluoride availability at the tooth surface. [35]

Role of Pedodontist in Fluoride Dentifrice

The decision to use fluoride should be completely dependent on the caries risk of a given patient.

These guidelines have to be tailored to meet individual needs.[40] It is especially critical that dentists provide counseling to caregivers involving the use of oral description, visual aids and actual demonstration to help ensure that the appropriate amount of toothpaste is used.[41]

The ADA also emphasizes the importance of the professional verbal information given to parents and caregivers, followed by active demonstration of the amount of dentifrice to be used.[42]

In light of this, oral health care providers should discuss with caregivers the risk of developing fluorosis versus the benefit of reducing the risk for developing dental caries when providing oral health education.[41]

Majority of the respondents' i.e., 97% in group 1 and 63% in group 2 had never been explained about the correct method of use of fluoride paste in children.[20]

Supervision of tooth brushing with fluoride toothpaste is recommended as an effective caries prevention measure (recommendation grade A). The AAPD recommendations encourage the use of 5% fluoride varnish at least once every six months in children with high caries risk.[40]

Good practice points on brushing behaviour:

- Tooth brushing should be conducted so each tooth surface is reached and brushing should exceed 1 min, also in preschool children.
- Children should avoid rinsing with a lot of water afterwards.
- Children's teeth should be brushed using either a soft manual or power toothbrush.[22]

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