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Review Article

Fluoride in dentistry: benefits, risks, and public health implications

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ABSTRACT

Dental caries is the localized destruction of dental hard tissues resulting from the acidic by-products, which are produced by the bacteria present in the oral cavity. Dental caries is considered the most common health condition affecting humanity, affecting 2.3 billion people worldwide. As a result, minimally invasive dentistry was developed to treat dental caries at an early stage and to decrease the high prevalence of dental caries among children and adults. Fluoride is one of the main components used in preventive measures in dentistry and in minimally invasive dentistry. It can inhibit enamel and dentin demineralization and induce enamel remineralization due to the replacement of fluoride ions with hydroxyl groups in the enamel hydroxyapatites, forming fluorohydroxyapatite, which has greater stability and reduced solubility in an acidic medium. Moreover, fluorapatite exhibits the lowest solubility and the greatest stability in the acidic medium. When these components are integrated into the composition of the enamel, it becomes more resistant to demineralization. Despite the presence of several studies confirming the benefits of fluoride in dentistry, it can result in multiple complications, such as dental fluorosis, skeletal fluorosis, and acute fluoride toxicity. Therefore, many countries have developed community water fluoridation to reduce the prevalence of dental caries. However, many individuals debated the ethics of community water fluoridation; therefore, several countries have developed alternatives to water fluoridation, such as fluoride in salt and milk. Therefore, policymakers should provide a regulatory framework that balances the benefits of community water fluoridation and preserves the public's right. Additionally, caregivers and parents should be educated about the importance of topical fluoride, either in toothpastes or the topical fluoride that is applied professionally by dentists, to prevent the prevalence of dental caries in children.

Keywords: Fluoride, Dentistry, Water fluoridation, Dental caries, Dental fluorosis

INTRODUCTION

Dental caries is defined as the localized destruction of dental hard tissues resulting from the acidic by-products produced by bacteria present in the oral cavity after fermenting the ingested carbohydrates.[1] Dental caries is considered the most common health condition affecting humanity, affecting 2.3 billion people worldwide.[2,3] Dental caries is prevalent in children as well, affecting 46.9% of children aged 1 to 4 years old and 39.3% of children aged 5 to 9 years old.[4] Therefore, minimal intervention dentistry was developed to treat dental caries at an early stage, aiming to decrease the high prevalence of dental caries among children and adults.[5] The goal of minimal intervention dentistry is to conservatively treat dental caries to maintain the tooth for life.[5] This can only be achieved through the early diagnosis, risk assessment, remineralization of the demineralized enamel and dentin, minimally invasive restorative intervention, repair rather than replace, and optimal caries preventive measures.[6] Minimal intervention dentistry protocols include the atraumatic restorative technique, which is used for sealants

and restorations, the Hall technique, which is used for sealing carious lesions in primary molars using preformed stainless steel crowns, and using diamine fluoride for caries arrest and prevention.[7-9]

Fluoride is one of the main components used in preventive measures in dentistry. It has the ability to inhibit dental hard tissue demineralization and induce enamel remineralization.[10] This property is attributed to the ability of fluoride ions to partially replace the hydroxyl groups in the enamel hydroxyapatites and form fluorohydroxyapatite, which has greater stability and reduced solubility in an acidic medium compared to the pure hydroxyapatite crystals.[10,11] Moreover, if the fluoride ions completely replace the hydroxyl groups, they form fluorapatite, which exhibits the lowest solubility and the greatest stability in the acidic medium. These components render enamel more resistant to demineralization.

Additionally, the presence of fluoride ions in the saliva or the dental plaque stabilizes the calcium and phosphate ions near the tooth, hence facilitating the remineralization of the tooth into demineralized enamel lesions.[10] Fluoride has an antibacterial effect, specifically against *Streptococcus mutans*, which is the primary causative pathogen in dental caries. Fluoride inhibits the enolase enzyme produced by bacteria, which decreases their acid production, hence diminishing their cariogenic ability.[12,13] Despite the remineralizing effect of fluoride, its benefits can be attenuated by the conditions of the oral cavity. For instance, if the plaque biofilm is thick, it reduces the ability of the fluoride ions to diffuse to the enamel crystals. Further attenuation can be caused by the limited buffering capacity of the saliva, reduced salivary flow, and variations in the biofilm matrix, which inhibit the cariostatic effect of fluoride.[13] This review article aims to discuss the risks, benefits, and public health implications of fluorides in dentistry. It seeks to elucidate the crucial role of fluoride in preventive and minimally invasive dentistry by highlighting its cariostatic and antibacterial potential. Moreover, it highlights the risks of improper and overuse of fluoride and its negative outcomes. This review article aims to add to the existing literature that discusses the role of fluoride in preventive dentistry.

METHODS

This narrative review is based on a comprehensive literature search conducted on 24 November 2025, using ScienceDirect, PubMed, Wiley Library, Dynamed, MDPI, Oxford Academic, BMC, and Cochrane databases. The research utilized Medical Subject Headings (MeSH) terms and relevant keywords, such as benefits and risks of fluoride use in dentistry, to identify studies that examined the risks, benefits, and public health implications of fluoride use in dentistry. A manual search was also conducted using Google Scholar, and the reference lists of identified papers were reviewed to locate additional relevant studies. No restrictions were applied regarding publication date, language, participant age, or type of publication, ensuring a broad and inclusive exploration of the available literature.

DISCUSSION

Benefits of systemic fluoride versus topical fluoride

Many studies reported that the ingestion of fluoride during the pre-eruptive stage resulted in a significant decrease in the prevalence of caries in permanent and primary teeth.[14] Moreover, the residents in areas with fluoridated drinking water were found to have fewer carious lesions. Additionally, the systemic ingestion of fluoride during the prenatal stage reduced the caries prevalence in the deciduous teeth.[15,16] LeGeros et al reported that children who were subjected to prenatal fluoride supplementation exhibited homogeneous and less extensive patterns of acid etching, larger prism dimensions, denser crystals in the intraprismatic regions, greater total mineral density, a higher degree of crystallinity, and more fluoride content.[17] Moreover, Hellwig et al reported in their study that children between the ages of 12.5-16, who were exposed to fluoridated water all their lives, exhibited a lower prevalence of dental caries.[18] However, Künzel et al reported that despite the change in the concentration of fluoridated water in their study, the prevalence of dental caries remained at a lower rate, which is attributed to other topical sources of fluoride.[19]

Multiple studies provided evidence that confirms the caries-preventive effect of topical fluoride. For instance, toothpastes containing ≥1000 ppm fluoride can reduce caries incidence by 23% in children and adolescents in comparison to non-fluoridated toothpastes.[12,20] Whereas fluoride mouth rinses can reduce caries incidence by 27% in children and adolescents.[21] However, topical fluorides applied directly to the teeth exhibited greater reduction in caries incidence than other topical fluorides. For example, fluoride varnish was found to reduce caries incidence in deciduous teeth by 37% and in permanent teeth by 43%, when applied two to four times annually. However, the effect of topical fluorides is attenuated by the lack of compliance.[22]

The application of topical fluoride is essential in high-risk populations. For instance, in older patients, the use of fluoride varnishes, fluoride toothpastes, or fluoride mouth rinses can significantly reduce root caries resulting from gingival recession and xerostomia.[23] Patients with fixed orthodontic appliances can prevent the development of whit spot lesions and enamel demineralization by the regular use of fluoride toothpastes.[24] Young children with early childhood caries, who cannot receive conventional treatment, can benefit from the cariostatic effect of topical fluoride through the use of silver diamine fluoride (SDF).[25]

Applications of topical fluoride

Fluoride toothpaste is the most common fluoride application due to its accessibility for most of the

population.[12] The most common fluoride compounds used are stannous fluoride (SnF_2), sodium monofluorophosphate, or sodium fluoride. These compounds significantly inhibit demineralization and stimulate remineralization, resulting in a significant reduction in the prevalence of dental caries.[26] The combination of amine fluoride and SnF_2 in toothpastes provides a synergistic effect, combining the anti-microbial and cariostatic properties of SnF2 and amine fluoride, respectively.[27] For adults, the standard concentration of fluoride in toothpastes ranges between 1000 to 1500 ppm.[26] High-risk adults who have rampant caries, xerostomia, or fixed orthodontic appliances are recommended to use toothpastes with a concentration of 5000 ppm.[12] Whereas the recommended fluoride concentration in children under six is between 500 and 1000 ppm to avoid the incidence of dental fluorosis, since children may swallow the toothpaste. Additionally, the guidelines recommend that children use pea-sized fluoride toothpastes under the supervision of their parents or caregivers to avoid systemic fluoride exposure.[28]

Another fluoride delivery vehicle is fluoride mouth rinse. They contain fluoride with a lower concentration, ranging between 230 ppm for daily use or 900 ppm for weekly use. They have a significant effect in reducing the incidence of dental caries; however, the suboptimal adherence to it often causes weak results. Mouth rinses are not recommended for children under the age of six years old, due to the high risk of ingestion, resulting in systemic toxicity.[28]

Fluoride varnishes are topical agents placed professionally by dentists to deliver high concentrations of fluoride directly to the tooth. They often contain 5% sodium fluoride with fluoride concentrations of 22,600 ppm.[12,29] These varnishes adhere to the enamel surface of the tooth, allowing sustained release of fluoride to inhibit the demineralization process, stimulate the remineralization process, and inhibit the cariogenic effect of bacteria. Fluoride varnishes can significantly reduce the incidence of dental caries up to 43% in permanent teeth if applied two to four times annually.[29] Fluoride varnishes have been proven beneficial for high-risk populations, cases of exposed roots, patients with fixed orthodontic appliances, and children under the age of six.[10]

SDF is another topical fluoride agent applied professionally by dentists directly to the tooth. The difference between SDF and fluoride varnishes is that SDF is applied to a cavity to arrest further cavitation, whereas fluoride varnishes are applied to an intact tooth or a tooth with initial demineralization.[10,30] SDF has proven high efficacy in arresting carious lesions in pediatric patients. However, its only drawback is black staining (Figure 1).[31] Despite their significant role in arresting caries in young, uncooperative children with early childhood caries, a specific protocol has not been developed yet. SDF can be beneficial in cases of rampant caries and root caries in adults; however, further research is needed.[25]

Figure 1: Arrested caries after the application of SDF.

Risks of using fluoride in dentistry

Despite the proven benefits of fluoride in dentistry, its excessive exposure can lead to several complications, such as dental fluorosis. Dental fluorosis is caused by the excessive ingestion of fluoride during tooth development. The severity of the condition is directly related to the dose of the ingested fluoride and the extent of time to which the individual was exposed to it (Figure 2).[32,36] Excessive fluoride in the plasma interferes with the removal of amelogenins during the maturation of enamel, resulting in hypomineralized enamel.[33] The most susceptible population to dental fluorosis is children from birth to the age of eight. Water with a fluoride concentration of 1.5 ppm or more often causes enamel changes. The optimal level of fluoridated water is 1 ppm.[32] Dental fluorosis affects primary and permanent dentition and affects both genders equally. Its prevalence has increased in the United States from 23% to 41% in adolescents, which urged the department of health in the US to decrease the fluoride concentration from 1 ppm to 0.7 ppm.[32,34] In mild cases, the patient may not be concerned, and it requires no treatment, unless the patient demands it for aesthetic purposes. In these cases, bleaching can be very beneficial, yielding positive results.[35] In moderate cases, bleaching may yield optimal results; therefore, microabrasion of enamel and resin infiltration are recommended. If these treatment modalities did not result in a favorable outcome, a more invasive approach is followed using composite veneers or localized composite restoration to mask the discoloration. Whereas, in severe cases, indirect ceramic crowns or veneers are recommended.[35]

Acute and chronic fluoride toxicity is a serious risk that can result from excessive exposure or ingestion of large amounts of fluoride. Most ingestion incidents are reported among children. For instance, the American Association of Poison Control Centers recorded 10,596 calls reporting fluoride exposure. Approximately 33.4% of the exposures were attributed to dietary supplements, followed by fluoride toothpastes with 31.5%, vitamins (23.5%), and fluoride mouth rinses (11.5%).[37] Acute fluoride toxicity occurs immediately after a single ingestion of a large amount of fluoride compounds, such as sodium fluoride. These compounds are completely absorbed through the gastrointestinal tract. The absorption of the fluoride

compounds can be delayed if there is food or milk in the blood.[37] The levels of fluoride peaks in the plasma after one hour of ingestion, and most of the ingested fluoride is excreted in the urine. The symptoms of acute fluoride toxicity depend on the ingested dose of fluoride. In mild cases, acute fluoride toxicity is accompanied by nausea, vomiting, and stomachache. In severe cases, acute fluoride toxicity is accompanied by Convulsions, tetany, decreased myocardial contractility, hypocalcemia, hyperkalemia, ventricular arrhythmias, and cardiac arrest.[37]

Chronic fluoride toxicity can result in several local and systemic manifestations; one of the most common local manifestations is dental fluorosis.[36] Systemic manifestations of chronic fluoride toxicity include increased bone density, joint pain, skeletal deformities, joint pain, and disability.[38] Additionally, chronic fluoride toxicity was linked to decreased intelligence quotient (IQ) scores and cognitive outcomes.[3]

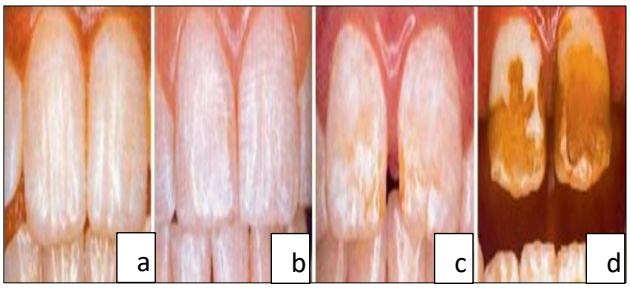

Figure 2 (a-d): Stages of dental fluorosis.

Public health implications

The chronic exposure to fluoride resulting from community water fluoridation, several debates were generated. It is argued that water fluoridation is considered a treatment without consent and negatively affects the autonomy of individuals in the community, which conflicts with the ethical principle of informed choice.[10] However, community water fluoridation has proven significant reduction in the incidence and prevalence of dental caries, which is considered a cost-effective treatment. Therefore, the Nuffield Council on Bioethics aimed to balance the significant benefits of community water fluoridation and the individuals' autonomy by suggesting that community water fluoridation should be determined through a local democratic process to preserve the rights of the community members.[10,40]

Additionally, water fluoridation differs in each country depending on the regulatory framework, cultural attitudes, and local geological conditions. For instance, in the U.S, the recommended water fluoride concentration was reduced to 0.7 ppm to reduce the risk of dental fluorosis and reduce the prevalence of dental caries.[41] Whereas in several European countries, the majority of the population opted against water fluoridation, therefore, alternative ways of fluoridation were used, such as fluoride in salt, fluoride in milk, and topical fluoride.[42] A similar public health policy was developed in Calgary, Canada, in which the discontinuation of community water fluoridation was followed by a significant increase in the prevalence of dental caries; however, the ethical debate of community water fluoridation prompted the development of a new policy in 2021, which redefined fluoridation and suggested using alternative ways of fluoridation.[43]

The significance of fluoride in the prevention of dental results in significant health implications. Although community water fluoridation has several benefits, and has exhibited a significant reduction in the prevalence of dental caries. However, the risks of dental fluorosis and the ethical considerations of community water fluoridation require the development of new policies to balance the benefits of fluoride and the rights of the local population.

CONCLUSION

Fluoride plays an essential role in preventing dental caries, inhibiting demineralization, and stimulating mineralization. Although there are several studies confirming the benefits of fluoride in dentistry, it can result in multiple complications, such as dental fluorosis, skeletal fluorosis, and acute fluoride toxicity. Therefore, many countries have developed community water fluoridation to reduce the prevalence of dental caries. However, due to ethical considerations and public opposition, many countries opted against community water fluoridation and replaced it with fluoride in salt and milk. Therefore, policymakers should provide a regulatory framework that balances the benefits of community water fluoridation and preserves the public's right. Additionally, caregivers and parents should be educated about the importance of topical fluoride, either in toothpastes or the topical fluoride that is applied professionally by dentists, to prevent the prevalence of dental caries in children.

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