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The multifaceted role of fluoride in preventing early childhood caries: A comprehensive review

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Abstract

Early childhood caries (ECC) remains a prevalent and significant public health concern worldwide, particularly in underserved communities. Fluoride has long been recognized as a cornerstone in ECC prevention due to its multifaceted mechanisms of action, including topical effects on enamel, systemic effects on dental development, antimicrobial properties, and the ability to promote remineralization of early carious lesions. This comprehensive review explores the various roles of fluoride in preventing ECC, encompassing its sources, efficacy, safety considerations, delivery strategies, challenges, and future directions. Community water fluoridation, fluoride toothpaste, mouth rinses, professional treatments, and dietary sources constitute primary means of fluoride exposure. Extensive clinical trials, epidemiological studies, meta-analyses, and systematic reviews provide robust evidence supporting the effectiveness of fluoride in reducing ECC prevalence and severity. However, optimizing fluoride exposure levels while minimizing the risk of dental fluorosis remains a critical consideration, especially in vulnerable populations. Strategies for fluoride delivery in high-risk groups, such as early childhood interventions, school-based programs, and community outreach initiatives, play pivotal roles in promoting oral health equity. Nevertheless, challenges persist, including limited access to fluoride in underserved areas, public misconceptions, and the need for further research on novel fluoride formulations. Fluoride continues to be a vital tool in ECC prevention, with implications for both clinical practice and public health policy. Addressing disparities in fluoride access and enhancing community engagement are essential for maximizing its impact in reducing ECC burden globally. Future research endeavors should focus on innovative approaches to fluoride delivery and long-term oral health outcomes in diverse populations.

Keywords: Multifaceted; Fluoride; Early Childhood Caries; Underserved communities

1 Introduction

Early childhood caries (ECC) poses a significant public health challenge globally, particularly among vulnerable populations such as children from low socioeconomic backgrounds and minority groups (Pierce et al., 2019). ECC, defined as the presence of one or more decayed, missing, or filled teeth in children under the age of six, can have profound consequences on a child's overall health, development, and quality of life. The importance of preventing ECC cannot be overstated, as it can lead to pain, infection, difficulty eating, impaired speech development, and compromised academic performance. Moreover, ECC can set the stage for future dental problems, increasing the risk of caries in permanent teeth and other oral health issues later in life (Zou et al., 2022). Fluoride has long been recognized as one of the most effective and cost-efficient measures for preventing dental caries, including ECC. Its significance in ECC prevention stems from its ability to strengthen tooth enamel, inhibit demineralization, promote remineralization of early lesions, and inhibit the growth of cariogenic bacteria. Fluoride can exert its protective effects through various routes of administration, including topical application (e.g., toothpaste, mouth rinses, and professional treatments) and systemic exposure (e.g., community water fluoridation and dietary sources) (O Mullane et al., 2016). The widespread

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availability and affordability of fluoride-containing products make it a feasible and scalable intervention for ECC prevention. The purpose of this review is to provide a comprehensive overview of the multifaceted role of fluoride in preventing ECC. By synthesizing existing evidence from clinical trials, epidemiological studies, meta-analyses, and systematic reviews, this review aims to elucidate the efficacy, safety considerations, delivery strategies, challenges, and future directions pertaining to fluoride use in ECC prevention (Smith et al., 2015). Furthermore, by highlighting the importance of ECC prevention and the pivotal role of fluoride, this review seeks to inform clinical practice, public health policy, and research agendas aimed at reducing the burden of ECC and promoting oral health equity among children worldwide.

1.1 Background on early childhood caries (ECC)

Early Childhood Caries (ECC) refers to the presence of one or more decayed (cavitated or non-cavitated), missing (due to caries), or filled tooth surfaces in primary teeth of children under the age of six. It represents a significant oral health concern globally, affecting millions of children, particularly those from disadvantaged backgrounds. The prevalence of ECC varies widely across different regions and populations, but it tends to be highest in socially deprived areas with limited access to dental care and preventive services (Olatosi et al., 2016). Studies have shown that ECC disproportionately affects certain demographic groups, including children from low-income families, minority populations, and those living in rural or underserved areas. Multiple factors contribute to the development of ECC, including biological, behavioral, environmental, and socio-economic determinants. Poor oral hygiene practices, frequent consumption of sugary snacks and beverages, prolonged bottle or breastfeeding beyond infancy, and inadequate exposure to fluoride are common behavioral risk factors associated with ECC (Anil and Anand, 2017). Furthermore, biological factors such as genetic predisposition to caries, saliva composition, and oral microbial flora play significant roles in ECC susceptibility. Environmental factors such as community water fluoridation status, access to dental care, and socio-economic factors like parental education, household income, and caregiver's oral health knowledge also influence ECC prevalence and severity. Untreated ECC can have profound consequences on a child's oral and overall health, development, and well-being. In the short term, ECC can cause pain, discomfort, difficulty eating, and sleeping disturbances, leading to poor nutritional intake and failure to thrive (Çolak et al., 2013). Moreover, untreated dental caries can progress rapidly, leading to dental abscesses, infections, and sepsis, requiring emergency dental interventions and hospitalizations. Long-term consequences of untreated ECC include early tooth loss, malocclusion, speech impediments, compromised aesthetic appearance, and negative psychosocial impacts such as low self-esteem and impaired social interactions. Furthermore, ECC can have economic ramifications for families and healthcare systems due to the costs associated with dental treatments, hospitalizations, and lost productivity. Addressing ECC prevention and early intervention is essential to mitigate its adverse outcomes and improve the overall health and well-being of affected children and their families (Saikia et al., 2022).

1.2 Fluoride: mechanisms of action

Fluoride exerts its preventive effects on dental caries through a variety of mechanisms, encompassing both topical and systemic actions. Understanding these mechanisms is essential for comprehending the role of fluoride in preventing early childhood caries (ECC) and promoting overall oral health (Folayan et al., 2023). One of the primary mechanisms by which fluoride prevents dental caries is through its topical effects on enamel. Fluoride interacts with the enamel surface, forming fluorapatite, a more acid-resistant crystalline structure than hydroxyapatite, the main mineral component of enamel. This fluoridated enamel is more resistant to demineralization by acids produced by cariogenic bacteria in dental plaque. Additionally, fluoride can inhibit bacterial enzyme activity, reducing the ability of bacteria to metabolize carbohydrates and produce acid, thereby further protecting the enamel from acid attacks (Ten Cate and Van Loveren, 1999). Fluoride ingested during tooth development can incorporate into the developing enamel, making it more resistant to acid dissolution. This systemic effect occurs primarily during the formation of the permanent dentition, but fluoride uptake by the developing primary teeth can also confer protection against caries. Systemic fluoride exposure through sources such as community water fluoridation and dietary supplements can contribute to the development of a more caries-resistant dentition in children. Fluoride exhibits antimicrobial properties, inhibiting the growth and metabolism of cariogenic bacteria such as Streptococcus mutans and Lactobacillus species. By disrupting bacterial metabolic pathways and reducing acid production, fluoride can help maintain a more balanced microbial ecosystem in the oral cavity, thereby reducing the risk of dental caries. Furthermore, fluoride can enhance the remineralization process by promoting the deposition of calcium and phosphate ions onto demineralized enamel surfaces, leading to the formation of fluorapatite and the reversal of incipient carious lesions. Fluoride plays a crucial role in promoting the remineralization of early carious lesions, which are characterized by localized demineralization of enamel due to acid exposure. Fluoride enhances the remineralization process by facilitating the deposition of calcium and phosphate ions from saliva onto demineralized enamel surfaces, leading to the formation of fluorapatite crystals and the arrest of caries progression (García-Godoy and Hicks, 2008). Additionally, fluoride can inhibit the activity of demineralization-promoting enzymes, further supporting the remineralization process and promoting the restoration

of enamel integrity. Fluoride's multifaceted mechanisms of action, including its topical effects on enamel, systemic effects on dental development, antimicrobial properties, and role in remineralization, collectively contribute to its efficacy in preventing dental caries, including ECC (Pitts et al., 2017). These mechanisms underscore the importance of fluoride as a cornerstone of ECC prevention strategies and highlight its potential for promoting oral health and reducing caries burden in children.

1.3 Sources of fluoride

Fluoride is available from various sources, each playing a significant role in preventing dental caries, including early childhood caries (ECC). Understanding these sources is crucial for implementing effective fluoride-based preventive strategies and promoting optimal oral health outcomes in children (O Mullane et al., 2016). Community water fluoridation (CWF) is widely recognized as one of the most cost-effective and equitable measures for preventing dental caries, reaching entire populations regardless of age, socioeconomic status, or access to dental care. CWF involves adjusting the fluoride concentration in public water supplies to an optimal level (typically 0.7-1.2 parts per million) to provide continuous, systemic exposure to fluoride. Numerous studies have demonstrated the effectiveness of CWF in reducing caries prevalence and severity, particularly among children, with significant public health benefits and cost savings over the long term (Kim et al., 2017). Despite its proven efficacy, CWF remains a contentious issue in some communities due to concerns about safety, ethics, and personal choice. Fluoride-containing toothpaste is a cornerstone of daily oral hygiene practices and a primary source of topical fluoride exposure for individuals of all ages. The mechanical action of brushing combined with the topical application of fluoride helps strengthen enamel, inhibit bacterial activity, and reduce the risk of dental caries. Fluoride mouth rinses, available in both over-the-counter and prescription formulations, provide an additional means of delivering fluoride to the oral cavity, particularly for individuals at higher risk of caries. However, caution should be exercised to ensure appropriate fluoride concentrations and adherence to recommended usage guidelines to minimize the risk of fluorosis, especially in young children. Professional fluoride treatments, administered by dental professionals during routine dental visits, offer targeted and concentrated fluoride exposure to individuals at increased risk of dental caries, including children with ECC (Phantumvanit et al., 2018). These treatments typically involve the application of fluoride varnish, gel, or foam directly to the teeth, providing a high concentration of fluoride for enhanced remineralization and caries prevention. Professional fluoride treatments are particularly beneficial for individuals with compromised oral hygiene, developmental disabilities, or medical conditions that predispose them to dental caries. Regular application of professional fluoride treatments can supplement other fluoride sources and provide additional protection against caries. In addition to exogenous sources such as fluoridated water, toothpaste, and professional treatments, fluoride can also be obtained from dietary sources, although to a lesser extent (Lussi et al., 2012). Foods and beverages processed with fluoridated water, such as beverages, canned goods, and processed foods, can contribute to overall fluoride intake. However, the fluoride content of foods and beverages varies widely depending on factors such as geographical location, food processing methods, and natural fluoride levels in water sources. While dietary sources of fluoride may contribute to overall fluoride exposure, their impact on caries prevention is relatively modest compared to other sources such as fluoridated water and toothpaste. Fluoride is available from multiple sources, each playing a vital role in preventing dental caries, including ECC. Community water fluoridation, fluoride toothpaste and mouth rinses, professional fluoride treatments, and dietary sources collectively contribute to achieving optimal fluoride exposure and promoting oral health in children and individuals of all ages. Effective utilization of these fluoride sources, coupled with education, outreach, and equitable access to dental care, is essential for reducing caries burden and improving oral health outcomes in communities worldwide (Northridge et al., 2020).

1.4 Efficacy of fluoride in ECC prevention

Fluoride has been extensively studied for its efficacy in preventing dental caries, including early childhood caries (ECC), through a wealth of clinical trials, epidemiological studies, meta-analyses, and systematic reviews (Utomo et al., 2023). This section delves into the robust evidence supporting fluoride's effectiveness in ECC prevention and highlights key findings from various research methodologies. Numerous clinical trials and epidemiological studies have investigated the impact of fluoride interventions on ECC prevalence, severity, and incidence. These studies often compare fluoride-exposed populations (e.g., communities with fluoridated water or individuals using fluoride toothpaste) to non-fluoride-exposed populations to assess the relative efficacy of fluoride in preventing ECC. Clinical trials typically involve randomized controlled trials (RCTs) or quasi-experimental designs, while epidemiological studies utilize observational methods such as cohort studies, cross-sectional surveys, and case-control studies (Gamble, 2014). Findings from clinical trials and epidemiological studies consistently demonstrate the significant protective effect of fluoride against ECC. Children exposed to fluoride, either through community water fluoridation, fluoride toothpaste, or other fluoride interventions, exhibit lower rates of caries prevalence, reduced severity of lesions, and decreased incidence of new carious lesions compared to non-fluoride-exposed counterparts. Moreover, longitudinal studies have shown that sustained exposure to fluoride from early childhood through adolescence yields long-term benefits in terms of caries

prevention and oral health outcomes. Meta-analyses and systematic reviews provide comprehensive summaries and quantitative assessments of the collective evidence from multiple studies on fluoride's efficacy in ECC prevention (Soares et al., 2021). These studies synthesize data from clinical trials, epidemiological studies, and other sources to derive pooled estimates of fluoride's effect size and assess the overall strength of evidence supporting its use. Meta-analyses and systematic reviews consistently confirm the substantial preventive effect of fluoride against ECC. Pooled analyses of randomized controlled trials and observational studies consistently demonstrate reductions in ECC prevalence, severity, and incidence associated with fluoride exposure (Moynihan et al., 2019). Moreover, meta-analyses have shown dose-response relationships between fluoride exposure levels and caries outcomes, with higher fluoride concentrations or longer exposure durations yielding greater reductions in ECC prevalence and severity. The collective evidence from clinical trials, epidemiological studies, meta-analyses, and systematic reviews provides robust support for the efficacy of fluoride in preventing ECC (Soares et al., 2021). These findings underscore the importance of fluoride as a cornerstone of ECC prevention strategies and highlight the need for continued efforts to promote fluoride use, expand access to fluoride interventions, and tailor preventive measures to meet the diverse needs of populations at risk for ECC. By leveraging the wealth of evidence on fluoride's efficacy, oral health professionals and policymakers can develop evidence-based strategies to reduce ECC burden and improve oral health outcomes in children worldwide.

1.5 Safety considerations

Fluoride is a potent preventive agent against dental caries, including early childhood caries (ECC), but its use necessitates careful consideration of safety concerns to minimize potential adverse effects (Kanagaratnam and Schluter, 2019). Determining the optimal fluoride exposure levels is essential to maximize caries prevention while minimizing the risk of adverse effects. The optimal fluoride concentration in community water fluoridation (CWF) is typically set between 0.7 and 1.2 parts per million (ppm), based on extensive research demonstrating the effectiveness of this range in reducing caries prevalence without significantly increasing the risk of fluorosis. Similarly, fluoride concentrations in toothpaste and mouth rinses are carefully formulated to provide sufficient caries protection while minimizing the risk of overexposure, especially in young children who may swallow toothpaste unintentionally. Individuals should be educated on the importance of using fluoride-containing products according to recommended guidelines, such as using a pea-sized amount of fluoride toothpaste for children under six years old and supervising their brushing to minimize ingestion. Additionally, healthcare professionals should consider factors such as age, risk of caries, and exposure to other fluoride sources when determining optimal fluoride interventions for patients (Rozier et al., 2010).

Dental fluorosis is a cosmetic condition characterized by the discoloration and mottling of tooth enamel, resulting from excessive fluoride intake during tooth development. The risk of fluorosis is highest during the developmental stages of teeth, particularly in children aged 8 and younger. Mild fluorosis presents as white streaks or spots on the enamel, while severe fluorosis can manifest as brown stains, pits, or surface irregularities (Ibiyemi, 2016). The risk of fluorosis is influenced by various factors, including fluoride intake from multiple sources, individual susceptibility, and timing of fluoride exposure. Community water fluoridation programs strive to maintain fluoride concentrations within the optimal range to minimize the risk of fluorosis while maximizing caries prevention. Individuals at higher risk of fluorosis, such as those living in areas with naturally high fluoride levels in water or using fluoride supplements, should be monitored closely to prevent excessive fluoride intake.

While fluoride primarily exerts its effects locally in the oral cavity, concerns have been raised regarding potential systemic effects associated with chronic fluoride exposure (O Mullane et al., 2016). High levels of fluoride intake, particularly from sources such as water contamination or excessive fluoride supplementation, can lead to skeletal fluorosis, a debilitating bone disorder characterized by bone pain, stiffness, and increased fracture risk. However, skeletal fluorosis is rare in regions with optimal fluoride concentrations in water. Additionally, some studies have suggested potential associations between chronic fluoride exposure and other health outcomes, such as thyroid dysfunction, neurodevelopmental effects, and reproductive health issues. However, the evidence supporting these associations is inconclusive and subject to debate, with many studies facing methodological limitations and conflicting findings. While fluoride is considered safe and effective for preventing dental caries, careful monitoring and adherence to recommended guidelines are essential to minimize potential safety concerns. By ensuring optimal fluoride exposure levels, educating individuals on proper fluoride use, and monitoring fluoride intake, healthcare professionals can mitigate the risk of adverse effects while maximizing the oral health benefits of fluoride in preventing ECC and promoting overall oral health (O Mullane et al., 2016).

1.6 Strategies for fluoride delivery in high-risk populations

High-risk populations, including children from low-income families, minority groups, and underserved communities, often face disparities in access to preventive dental care and fluoride interventions (Northridge et al., 2020).

Implementing targeted strategies for fluoride delivery in these populations is crucial for reducing the burden of early childhood caries (ECC) and promoting oral health equity.

1.6.1 Early childhood interventions

Early childhood interventions play a pivotal role in preventing ECC and promoting oral health from infancy through early childhood. These interventions target parents, caregivers, and healthcare providers to promote oral hygiene practices, dietary habits, and fluoride use in young children. Key components of early childhood interventions include anticipatory guidance on infant oral care, promotion of breastfeeding and appropriate bottle-feeding practices, introduction of fluoride toothpaste at an early age, and regular dental visits starting from the eruption of the first tooth (Casamassimo and Nowak, 2009). Home-based fluoride interventions, such as fluoride varnish applications by healthcare providers or community health workers, can also be implemented to provide targeted fluoride exposure to young children in high-risk populations. These interventions are often integrated into well-child visits, Head Start programs, or community-based clinics to reach underserved families with limited access to dental care. Additionally, education and outreach efforts should emphasize the importance of establishing a dental home and accessing preventive dental services early in life to prevent ECC and promote overall oral health (Kanagaratnam and Schluter, 2019).

1.6.2 School-based fluoride programs

School-based fluoride programs offer a promising approach to reach children in high-risk populations and provide fluoride interventions in a convenient and accessible setting (Abuhaloob et al., 2024). These programs typically involve the application of fluoride varnish or fluoride mouth rinses by dental professionals or trained school personnel in school settings. School-based fluoride programs can complement other fluoride delivery strategies, such as community water fluoridation and home-based fluoride interventions, to maximize fluoride exposure and caries prevention in children. School-based fluoride programs not only provide targeted fluoride interventions but also offer opportunities for oral health education, dental screenings, and referrals for follow-up care. By integrating oral health promotion into school curricula and leveraging existing school health infrastructure, these programs can reach large numbers of children, including those from disadvantaged backgrounds, and help reduce oral health disparities. Collaborative efforts between schools, public health agencies, dental professionals, and community organizations are essential for the successful implementation and sustainability of school-based fluoride programs (Gargano et al.,2019).

1.6.3 Community outreach initiatives

Community outreach initiatives play a vital role in engaging high-risk populations and promoting oral health awareness, access to dental care, and fluoride interventions. These initiatives involve partnerships between healthcare providers, community organizations, faith-based groups, schools, and local government agencies to deliver oral health education, screenings, fluoride treatments, and preventive services to underserved communities. Mobile dental clinics, community health fairs, and outreach events provide opportunities to reach individuals who may face barriers to accessing traditional dental care settings (National Research Council et al., 2012). Community health workers, promotores de salud, and peer educators can serve as trusted messengers and cultural liaisons, delivering culturally competent oral health messages and facilitating access to fluoride interventions for high-risk populations. Community water fluoridation advocacy efforts and policy initiatives can promote equitable access to fluoridated water and support population-level fluoride interventions in underserved areas. By addressing social determinants of health, advocating for policy changes, and building community capacity, community outreach initiatives can empower high-risk populations to prioritize oral health, access fluoride interventions, and reduce the burden of ECC and other oral health disparities.

Implementing targeted strategies for fluoride delivery in high-risk populations is essential for reducing the prevalence of early childhood caries (ECC) and promoting oral health equity (Kanagaratnam and 1Schluter, 2019). Early childhood interventions, school-based fluoride programs, and community outreach initiatives offer effective approaches to reach underserved communities, deliver fluoride interventions, and empower individuals to prioritize oral health. By leveraging partnerships, resources, and innovative approaches, stakeholders can work together to address oral health disparities and improve oral health outcomes for all children.

1.7 Challenges and future directions

Despite the proven effectiveness of fluoride in preventing dental caries, including early childhood caries (ECC), several challenges persist in ensuring equitable access to fluoride interventions and optimizing their use (Çolak et al., 2013). Additionally, ongoing research on novel fluoride formulations holds promise for enhancing caries prevention and addressing emerging oral health concerns.

1.7.1 Access to fluoride in underserved communities

Access to fluoride interventions remains a significant challenge in underserved communities, including rural areas, low-income neighborhoods, and minority populations (Northridge et al., 2020). Disparities in access to fluoridated water, dental care, and preventive services contribute to unequal oral health outcomes and exacerbate existing health inequities. Community water fluoridation (CWF) is an effective population-based approach to fluoride delivery, but its implementation and maintenance require political will, community engagement, and financial resources. Addressing barriers to CWF expansion, such as opposition from anti-fluoridation groups, funding constraints, and infrastructure challenges, is essential for increasing access to fluoride in underserved communities. Furthermore, innovative approaches, such as point-of-use water fluoridation devices, fluoride varnish programs, and community-based fluoride initiatives, can complement CWF and provide targeted fluoride interventions to high-risk populations (O Mullane et al., 2016)p. Collaborative efforts between public health agencies, dental professionals, community organizations, and policymakers are needed to overcome barriers to fluoride access and promote oral health equity for all.

1.7.2 Public perception and acceptance

Public perception and acceptance of fluoride interventions play a critical role in their effectiveness and uptake (Peckham and Awofeso, 2014). Misinformation, misconceptions, and fear-mongering campaigns propagated by anti-fluoridation groups can erode public trust in fluoride's safety and efficacy, leading to decreased acceptance of fluoride interventions and decreased adherence to recommended fluoride use guidelines. Addressing public concerns and promoting accurate information about fluoride's benefits and safety are essential for fostering trust and acceptance among individuals and communities. Health education campaigns, public awareness initiatives, and targeted messaging can help dispel myths and misconceptions surrounding fluoride and promote evidence-based oral health practices. Engaging with community leaders, stakeholders, and opinion influencers can build support for fluoride interventions and foster a culture of oral health promotion. Additionally, incorporating oral health education into school curricula and healthcare settings can empower individuals to make informed decisions about fluoride use and prioritize oral health as an integral component of overall well-being (World Health Organization, 2003).

1.7.3 Emerging research on novel fluoride formulations

Advances in dental science and technology have spurred research into novel fluoride formulations aimed at enhancing caries prevention, minimizing adverse effects, and addressing emerging oral health challenges (Fejerskov et al., 2015). Researchers are exploring innovative approaches, such as bioavailable fluoride compounds, nanoparticle delivery systems, and smart materials, to improve fluoride efficacy, bioavailability, and targeted delivery to caries-prone sites. For example, bioactive glass-based materials and calcium phosphosilicate compounds have shown promise in promoting remineralization and repairing early carious lesions. Nanostructured materials, such as calcium fluoride nanoparticles and fluoride-releasing nanocomposites, offer controlled fluoride release and enhanced penetration into enamel, leading to improved caries prevention (Melo et al., 2013). Smart materials embedded with fluoride reservoirs or remineralization agents can provide sustained protection against caries while minimizing fluoride exposure and adverse effects. Furthermore, research into personalized fluoride interventions, genetic susceptibility testing, and risk assessment models holds potential for tailoring fluoride recommendations to individual needs and optimizing caries prevention strategies (Pitts and Zero, 2016). By harnessing the latest scientific advances and technological innovations, researchers can continue to push the boundaries of fluoride research and develop next-generation fluoride formulations that offer superior efficacy, safety, and precision in preventing ECC and promoting oral health (Mutreja et al., 2023).

Addressing challenges in access to fluoride, public perception, and acceptance, while advancing research on novel fluoride formulations, is essential for maximizing fluoride's impact in preventing early childhood caries and improving oral health outcomes. By adopting a multi-faceted approach that combines community engagement, education, advocacy, and research innovation, stakeholders can work together to overcome barriers, promote evidence-based fluoride interventions, and achieve oral health equity for all children (de Lara and Frazão, 2021).

2 Conclusion

Fluoride remains a cornerstone in the prevention of dental caries, including early childhood caries (ECC), with its multifaceted mechanisms of action and widespread availability in various forms. This review has highlighted the critical role of fluoride in ECC prevention, examined its efficacy, safety considerations, delivery strategies, challenges, and future directions. Fluoride exerts its preventive effects on ECC through topical effects on enamel, systemic effects on dental development, antimicrobial properties, and remineralization of early carious lesions. Community water fluoridation, fluoride toothpaste, mouth rinses, professional treatments, and dietary sources are primary means of fluoride exposure. Extensive evidence from clinical trials, epidemiological studies, meta-analyses, and systematic reviews supports the

effectiveness of fluoride in reducing ECC prevalence, severity, and incidence. Safety considerations include optimizing fluoride exposure levels, minimizing the risk of dental fluorosis, and addressing potential systemic effects.

Healthcare professionals should promote fluoride use as a fundamental component of ECC prevention strategies and encourage adherence to recommended fluoride guidelines. Policymakers should support community water fluoridation programs, implement targeted fluoride interventions in high-risk populations, and address barriers to fluoride access in underserved communities. Oral health education, outreach, and advocacy efforts are essential for increasing public awareness, dispelling myths about fluoride, and fostering acceptance of fluoride interventions.

Future research should focus on novel fluoride formulations, personalized fluoride interventions, and precision oral health strategies tailored to individual needs. Longitudinal studies are needed to assess the long-term effects of fluoride exposure on oral health outcomes, including caries prevention, dental fluorosis, and systemic health. Research on fluoride's potential systemic effects, genetic susceptibility to fluoride, and interactions with other environmental factors can further our understanding of fluoride's safety and efficacy. Fluoride remains a vital tool in ECC prevention, with implications for both clinical practice and public health policy. By addressing challenges in fluoride access, public perception, and advancing research on novel fluoride formulations, stakeholders can work together to reduce ECC burden, promote oral health equity, and improve oral health outcomes for children worldwide.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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