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FLUORIDE RELEASE BY GLASS IONOMER CEMENTS: BENEFITS, RISKS, AND DEBATES

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ABSTRACT

Fluoride has a complex impact on human health, offering both positive and negative systemic effects. It is well-established as a crucial component in the prevention and treatment of dental caries, primarily due to its ability to strengthen enamel against acid decay and support remineralization. For many years, fluoride has been added to community water supplies in numerous regions, bringing significant benefits, especially in reducing dental cavities in children. However, a strong opposition to fluoride use in public water systems and as a food additive has emerged, with critics raising concerns about its safety. Recently, in the United States, the issue was reignited when a court ruling suggested that water fluoridation could pose unreasonable health risks, including a potential decrease in children's IQ. Additionally, statements from the US Department of Health and Human Services have sparked further debate, with some suggesting that the risks of fluoride may outweigh its benefits. This article aims to revisit the topic of fluoride, exploring its advantages, ongoing controversies, and potential risks. The review addresses the dual role of fluoride in both personal dental care and public health, emphasizing the need for careful and equitable strategies for its application to ensure safety and effectiveness.

Keywords: Fluoride, dental caries, healthcare, water fluoridation, topical fluoride, fluoride toxicity.

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ВЫДЕЛЕНИЕ ФТОРА СТЕКЛОИОНОМЕРНЫМИ ЦЕМЕНТАМИ: ПРЕИМУЩЕСТВА, РИСКИ И ДИСКУССИИ

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АННОТАЦИЯ

Фтор оказывает сложное воздействие на здоровье человека, включая как положительные, так и отрицательные системные эффекты. Он хорошо известен как важный компонент в профилактике и лечении кариеса благодаря своей способности укреплять эмаль, защищая её от разрушения кислотами, и способствовать реминерализации. В течение многих лет фтор добавлялся в водопроводную воду в различных регионах мира, что приносило значительную пользу, особенно в снижении уровня кариеса у детей. Однако против использования фтора в общественных водоснабжающих системах и в качестве пищевой добавки высказывается всё больше критики, связанной с вопросами его безопасности. Недавно в США эта тема вновь стала актуальной после судебного решения, в котором утверждалось, что фторирование воды может представлять собой неоправданный риск для здоровья, включая возможное снижение уровня IQ у детей. Кроме того, заявления Министерства здравоохранения и социальных служб США вызвали дополнительные дебаты — некоторые специалисты полагают, что потенциальные риски от фтора могут превышать его пользу. Цель данной статьи — вновь рассмотреть вопрос о фторе, исследуя его преимущества, продолжающиеся споры и возможные риски. В обзоре рассматривается двойственная роль фтора в индивидуальном уходе за полостью рта и в системе общественного здравоохранения, подчёркивая необходимость осторожного и справедливого подхода к его применению для обеспечения безопасности и эффективности.

Ключевые слова: фтор, кариес, здравоохранение, фторирование воды, местное применение фтора, токсичность фтора.

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INTRODUCTION

Oral health is a crucial aspect of overall health, influencing essential functions such as communication, facial expressions, sensory perception (taste and smell), touch, chewing, swallowing, and the ability to express emotions without discomfort or pain in the craniofacial region. The Global Report on Oral Health by the World Health Organization (WHO) in 2022 highlights the urgent need to incorporate oral health into the broader context of non-communicable diseases (NCDs) [1]. According to the 2015 Global Burden of Disease Study, untreated dental caries in permanent teeth is the most prevalent oral condition, affecting approximately 2.5 billion people worldwide, with an age-standardized prevalence of 34.1%. In primary teeth, untreated caries affected 573 million children, corresponding to a 7.8% age-standardized prevalence [2].

Caries prevention can be achieved through both community-based and individual interventions. Effective prevention strategies focus on managing biofilm, modifying oral microorganisms, and encouraging a low-sugar diet to reduce caries risk and halt lesion progression [3]. Fluoride plays an essential role in caries prevention, with various delivery methods designed to address specific needs for promoting oral health. Topical fluoride, applied directly to the tooth surface, includes self-applied methods such as fluoride toothpaste, mouth rinses, and gels, as well as professionally administered techniques like fluoride varnishes, solutions, gels, and dental materials. These methods enhance enamel remineralization and resistance to acid attacks. On the other hand, systemic fluoride is ingested and incorporated into developing teeth and bodily fluids like saliva, offering long-term protection. Common systemic fluoride delivery systems include community water fluoridation, school water programs, fluoride supplements, fluoridated salt, and milk fluoridation. Together, these methods form a comprehensive strategy for caries prevention tailored to meet the needs of both individuals and communities [4].

Community water fluoridation has been practiced since the 1950s and is regarded as an effective and efficient way to deliver fluoride on a large scale to populations. Numerous international studies have conclusively shown that water fluoridation leads to a significant reduction in caries levels in communities, compared to those with little or no fluoride. The CDC recognized water fluoridation as one of the ten great public health achievements between 1990 and 1999 [5]. Given this extensive body of evidence, the FDI World Dental Federation has long supported the inclusion of systemic fluoride in public health policies, emphasizing its role in preventing dental caries and improving global oral health. The organization has reiterated the importance of this in a new communiqué, particularly as global caries levels remain high and resistant to improvement [6].

Fluoride has both beneficial and harmful systemic effects on humans. Since the introduction of fluoride into community water supplies, a vocal anti-fluoride movement has emerged in many parts of the world, opposing its use in water supplies and as food additives. This issue was recently revived in the United States when, on September 24, 2024, a California District Court ruled in the case Food & Water Watch Inc. v. the US Environmental Protection Agency (EPA). The court’s decision stated that if the EPA denies a petition from a US resident concerned about fluoride, that resident is entitled to judicial review regarding whether the chemical poses an unreasonable risk, regardless of the EPA's interpretation of the data. The judge also ruled that community water fluoridation presents a risk of reduced IQ in children. This, along with new perspectives from the leadership of the US Department of Health and Human Services suggesting that water fluoridation may cause more harm than good, has reignited the debate surrounding fluoride in water and food [7,8].

The purpose of this article is to provide a contemporary perspective on fluoride by revisiting its benefits, controversies, and potential risks. Through a review of the scientific evidence and clinical practices surrounding fluoride use, this article aims to educate dental professionals and the general public on the safe and effective application of fluoride in dentistry [9].

MECHANISM OF FLUORIDE ACTION

Fluoride is widely recognized as an essential element in the prevention and management of dental caries due to its unique properties that target both bacterial activity and tooth mineral dynamics [13]. Its anticariogenic and antimicrobial effects have been extensively studied, establishing fluoride as a cornerstone of modern preventive dentistry. Fluoride works by interacting with the oral environment in multiple ways, influencing bacterial metabolism and enhancing tooth resistance to acid dissolution [14-16].

Enzymes such as ATPase, which regulates energy production, and enolase, crucial for glycolysis, are inhibited by fluoride, preventing the bacteria from efficiently metabolizing sugars. This not only reduces acid production but also impairs bacterial growth, reproduction, and biofilm formation [17,18]. Fluoride also reduces the production of extracellular polysaccharides by bacteria, helping disrupt biofilm integrity and reducing bacterial adhesion to tooth surfaces [19]. Furthermore, fluoride mitigates the production of vital bacterial enzymes such as immunoglobulin A protease, which breaks down host defenses, further highlighting its multifaceted action against cariogenic biofilms. Moreover, fluoride's ability to concentrate within dental plaque ensures that its protective effects are localized to areas at high risk of demineralization [20].

Beyond its effects on microbes, fluoride has a profound impact on tooth mineralization and demineralization dynamics. It enhances the remineralization process by encouraging the deposition of calcium and phosphate ions into demineralized areas of enamel [21]. This process is further strengthened by the formation of fluorine-containing apatites, such as fluorapatite and hydroxyfluorapatite, which are more resistant to acid attacks and demineralization than hydroxyapatite, the natural mineral in tooth enamel. Fluorine-containing apatites have unique structures that make enamel less soluble in acidic conditions, providing long-term protection against caries.

Epidemiological and laboratory evidence supports the notion that fluoride's predominant effects are topical and post-eruptive, emphasizing its importance throughout life, not just during childhood. When used consistently and appropriately, fluoride is most effective in small, sustained concentrations within dental plaque and saliva. This allows it to continuously interact with the oral environment, maintaining a balance that favors remineralization over demineralization. Contrary to earlier assumptions, fluoride is highly beneficial for adults, especially for individuals with demineralized enamel, as the uptake of fluoride is greater in compromised areas than in sound enamel [22].

In addition to its individual benefits, fluoride also contributes to public health as an integral part of community prevention programs, such as water fluoridation, which ensures equitable access to its protective effects. This dual role of fluoride—targeting both individual oral hygiene practices and broader public health initiatives—underscores its significance in controlling dental caries and improving oral health outcomes globally [23]. However, its effectiveness depends on regular exposure in optimal concentrations, making its integration into daily oral care routines and public health policies essential.

ADVERSE EFFECTS OF FLUORIDE

Fluoride is widely recognized as a vital nutrient, and when consumed within recommended limits, it is safe and beneficial for humans. However, exceeding these safe intake levels can result in negative health effects [24]. Excessive fluoride exposure has been linked to a range of conditions, including dental and skeletal fluorosis, as well as systemic issues such as gastrointestinal, neurological, and urinary complications [25].

ACUTE TOXICITY

Acute fluoride toxicity occurs when a large amount of fluoride is ingested over a short period. While fatal cases are rare, a dose of 5–10 mg F/kg body weight can lead to acute toxic effects, while lethal doses are typically in the range of

70–140 mg F/kg body weight [26]. Inhalation of fluoride can irritate the respiratory tract, causing symptoms like coughing and difficulty breathing [27]. Direct contact with liquid fluoride or its vapors can result in skin burns, and if exposed to the eyes, it can cause permanent vision damage.

When fluoride is ingested, it reacts with gastric acid to form hydrofluoric acid, a corrosive substance that can lead to symptoms such as nausea, vomiting, diarrhea, excessive salivation, and abdominal pain. In severe cases, this may progress to hemorrhagic gastroenteritis. Critical complications include hypocalcemia, which can cause irregular heart rhythms, heightened reflexes, and muscle spasms. If not treated promptly, respiratory failure may occur, which can be fatal [28].

CHRONIC TOXICITY

Chronic fluoride toxicity results from long-term exposure to fluoride levels that exceed safe limits, leading to conditions such as dental and skeletal fluorosis, along with systemic effects like weight loss, fatigue, and anemia [29].

Dental fluorosis occurs when excessive fluoride intake disrupts tooth development during enamel formation, particularly in children aged 6 to 8 years. This condition is rare in fully erupted teeth and is common in areas with high natural fluoride levels in drinking water. While mild fluorosis may improve enamel's resistance to decay due to increased fluoride content, severe fluorosis can damage enamel, making it more prone to cavities [30].

The safe daily intake of fluoride is considered to be 0.05 to 0.07 mg F/kg/day. Exceeding this limit increases the risk of fluorosis. Several factors, such as the total amount of fluoride consumed, the type of fluoride intake, kidney function, and bone metabolism rates, influence fluoride levels in the body. Fluorosis can cause porosity and irregular mineralization in enamel, particularly in the outer layers [31].

Fluorosis is most noticeable in permanent teeth, although primary teeth may also be affected due to fluoride transfer during pregnancy or shorter enamel formation periods in baby teeth. The condition often impacts the premolars, second molars, and upper incisors, with visible effects appearing on the incisal or occlusal areas of the enamel [32]. Mild fluorosis typically manifests as white spots, while severe forms can lead to enamel hypoplasia, pitting, fractures, and discoloration ranging from yellow to brown. In extreme cases, enamel loss and structural damage can alter the tooth's shape and function [33].

ENDEMIC SKELETAL FLUOROSIS

Endemic skeletal fluorosis is a chronic condition caused by long-term fluoride consumption at levels exceeding 8 ppm. It leads to increased bone density, ligament calcification, joint stiffness, and limited mobility. In severe cases, known as "crippling fluorosis," deformities can occur, and the spine and chest may become fixed in a certain position [34].

INCREASING OPPOSITION TO FLUORIDATION

Most cases of fluoride toxicity (over 80%) are found in children under six, primarily due to accidental ingestion of fluoride-containing products like toothpaste or mouthwash. Fluoride toxicity is less common in adults, particularly in developed countries. Acute fluoride poisoning often presents with gastrointestinal symptoms such as nausea, vomiting, and abdominal pain. In severe cases, it can lead to renal and cardiac dysfunction, coma, or even death. For children, toxic effects can appear with fluoride intake as low as 8.4 mg/kg [35]. Chronic fluoride toxicity is typically linked to prolonged exposure to high fluoride levels in drinking water or excessive use of fluoride supplements.

Long-term fluoride exposure can result in dental fluorosis, and in severe cases, it can lead to skeletal fluorosis, which increases bone density but decreases the structural integrity of bones, making fractures more likely. Rarely, the condition may lead to calcification of ligaments and tendons, restricting joint movement. In advanced stages, extensive calcification can occur, along with bony outgrowths like osteophytes and exostoses [36]. Prolonged fluoride exposure has also been associated with negative effects on the skeletal, reproductive, and other organ systems.

Concerns about fluoride toxicity have led to ongoing debates regarding fluoridation practices. Some nations have taken measures to limit fluoride exposure due to these risks. Several key issues have been raised:

CONCLUSIONS

Fluoride has been instrumental in preventing and managing dental caries through mechanisms such as enamel remineralization, inhibition of demineralization, and antimicrobial effects. Various fluoride delivery methods, including water, milk, and salt fluoridation, as well as toothpaste, have shown significant public health benefits, especially in reducing caries prevalence. However, concerns over fluoride toxicity, excessive intake, and potential systemic effects have sparked ongoing debates. While controlled fluoride exposure is essential for maximizing its dental benefits, unregulated consumption can lead to risks such as dental and skeletal fluorosis, and may have adverse effects on other systems.

The debate over fluoride highlights the importance of evidence-based public health policies that prioritize safety, efficacy, and equitable access. Given that fluoride's main benefits are topical, strategies emphasizing the use of fluoride toothpaste and professionally applied treatments may offer safer alternatives to systemic fluoridation. Further high-quality research, including randomized controlled trials, is necessary to assess long-term effects and refine fluoride recommendations. By balancing the preventive advantages of fluoride with the potential risks, policymakers and healthcare professionals can develop targeted approaches that ensure both effective caries prevention and overall public health safety.

ETHICAL STATEMENT AND CONSENT TO PARTICIPATION

The study was conducted in accordance with the local ethical committee.

CONFLICT OF INTERESTS

The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

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AVAILABILITY OF DATA AND MATERIALS

All data generated or analysed during this study are included in this published article.

AUTHORS' CONTRIBUTIONS

All authors contributed to the design and interpretation of the study and to further drafts. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All applicable international, national and/or institutional ethical guidelines have been followed.

CONSENT FOR PUBLICATION

Not applicable.

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КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что данная работа, её тема, предмет и содержание не затрагивают конкурирующих интересов.

ИСТОЧНИКИ ФИНАНСИРОВАНИЯ

Авторы заявляют об отсутствии финансирования при проведении исследования.

ДОСТУПНОСТЬ ДАННЫХ И МАТЕРИАЛОВ

Все данные, полученные или проанализированные в ходе этого исследования, включены в настоящую опубликованную статью.

ВКЛАД ОТДЕЛЬНЫХ АВТОРОВ

Все авторы внесли свой вклад в подготовку исследования и толкование его результатов, а также в подготовку последующих редакций. Все авторы прочитали и одобрили итоговый вариант рукописи.

ЭТИЧЕСКОЕ ОДОБРЕНИЕ И СОГЛАСИЕ НА УЧАСТИЕ

Были соблюдены все применимые международные, национальные и/или институциональные руководящие этические принципы.

СОГЛАСИЕ НА ПУБЛИКАЦИЮ

Не применимо.

ПРИМЕЧАНИЕ ИЗДАТЕЛЯ

Журнал *"Интегративная стоматология*

и челюстно-лицевая хирургия" сохраняет нейтралитет в отношении юрисдикционных претензий по опубликованным картам и указаниям институциональной принадлежности.

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