Review Article

Beyond Toothpaste: The Role of Intraoral Fluoride Devices in Oral Health Maintenance

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ABSTRACT:

Dental caries remains a significant concern, particularly among medically compromised individuals, those with mental disabilities, and the elderly. Fluoride has long been utilized as a preventive measure against dental caries through various modalities, including water fluoridation, systemic intake, and topical applications. Intraoral fluoride-releasing devices represent an innovative advancement in preventive dentistry, offering a targeted and sustained approach to reducing caries incidence. These devices provide controlled, long-term fluoride release directly into the oral cavity, ensuring optimal fluoride levels in saliva and dental plaque. This mechanism supports enamel remineralization, inhibits demineralization, and suppresses the activity of cariogenic bacteria. Diverse designs, such as fluoride-releasing elastomers, polymer-based systems, and bioadhesive materials, have demonstrated effectiveness in both clinical and experimental settings. This review examines the types and clinical applications of intraoral fluoride-releasing devices, emphasizing their role in caries prevention and potential directions for future research.

KEYWORDS: Dental caries, Fluoride, Intra oral fluoride-releasing devices.

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INTRODUCTION:

Dental caries occur when bacteria in dental plaque produce acids that progressively erode the enamel. Preventive measures include enhancing oral hygiene routines and utilizing a combination of chemical agents and physical methods to minimize dental plaque[1]. Fluoride is a powerful active ingredient that effectively prevents dental caries and aids in reversing and remineralizing early enamel lesions. It can be administered in several ways, such as through fluoridated drinking water, fluoride tablets or liquids, fluoride-containing mouth rinses, toothpaste, or food, as well as by applying fluoride solutions, gels, or varnishes directly to the teeth[2].

HISTORY OF FLUORIDE DEVICE USE IN DENTAL CARE:

The role of fluoride in dental care has been fundamental in reducing the incidence of tooth decay (caries). From the initial observations of its natural presence in water to the development of advanced fluoride delivery systems, fluoride has shaped the trajectory of modern dentistry. Over the years, various

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fluoride devices have been developed to aid in the topical application of fluoride to the teeth, enhancing remineralization and preventing caries. The evolution of fluoride device use reflects ongoing innovations in dental technology and preventive care.

Early Discoveries and the Rise of Fluoride Use:

Fluoride's beneficial effects in dental care were first noted in the early 20th century. In the 1930s and 1940s, researchers observed that individuals living in areas with naturally fluoridated water had lower rates of dental caries compared to those in areas with low fluoride levels. One of the pioneering studies by H. Trendley Dean (1942) demonstrated that fluoride in drinking water led to fewer cavities and improved dental health across populations, provided the fluoride concentration remained within a certain range. This groundbreaking work spurred the development of water fluoridation programs, which began in 1945 in Grand Rapids, Michigan, and later expanded globally[3].

However, while water fluoridation was a public health success, researchers also sought ways to target fluoride treatment to individuals who may not have access to fluoridated water, as well as to those at higher risk for cavities.

Fluoride Toothpaste and Topical Applications (1950s–1960s):

The introduction of fluoride toothpaste in the 1950s marked a major milestone in the widespread use of fluoride for dental care. In 1955, Procter & Gamble launched the first commercially available fluoride toothpaste under the brand Crest, which was later approved by the American Dental Association (ADA) in 1960. The active ingredient, sodium fluoride, was found to reduce dental caries by strengthening tooth enamel. Studies by Keyes et al. (1959) and Marquis et al. (1972) confirmed that fluoride toothpaste could significantly lower caries incidence in the population, making it one of the most effective preventive dental products available.

In addition to toothpaste, topical fluoride treatments like fluoride gels and mouth rinses also gained popularity in the 1960s. These concentrated treatments were designed for use by dental professionals, particularly for patients at high risk for caries, such as children and individuals with weakened enamel. These topical agents helped remineralize enamel and reduce the progression of early carious lesions[4,5].

The Advent of Intraoral Fluoride Devices (1970s-1980s):

As dental professionals sought more targeted and sustained fluoride delivery methods the 1970s saw the introduction of intraoral fluoride devices, aimed at providing prolonged fluoride exposure to individuals with specific needs.

a) The Copolymer Membrane Fluoride Device (1970s):

One of the early innovations in controlled fluoride release came in 1976 with the development of the copolymer membrane fluoride device by Cowsar et al.

This device utilized a fluoride-loaded copolymer matrix encapsulated within a thin, permeable membrane, designed to release fluoride ions gradually into the oral cavity. The primary advantage of this system was that it allowed for continuous fluoride delivery over an extended period, promoting remineralization of tooth enamel and helping to prevent caries. Cowsar and colleagues (1976) created a membrane-controlled reservoir system for fluoride release. The system consisted of an acrylic polymer matrix filled with granulated sodium fluoride (NaF), enclosed within a copolymer membrane. The core matrix was made from a 50/50 mixture of hydroxyethyl methacrylate (HEMA) and methyl methacrylate (MMA), while the surrounding membrane was made from a 30/70 HEMA/MMA copolymer. This membrane controlled the rate of fluoride release, ensuring a slow, sustained delivery. Each fluoride pellet within the device contained 35 mg of sodium fluoride and was designed to release an average of 0.12 mg of fluoride per day over a period of approximately 130 days. The rate of fluoride release was regulated by two factors: the degree of hydration of the matrix and the membrane's thickness, which acted to modulate the flow of fluoride ions. As the matrix absorbed moisture from the oral environment, the sodium fluoride gradually dissolved and moved through the membrane into the saliva. This process was governed by Fick's first law of diffusion, which states that the movement of ions follows a concentration gradient. The copolymer membrane fluoride device was typically attached to the buccal surface of the first permanent molar using either stainless steel retainers spot-welded to orthodontic bands or by directly bonding the device to the tooth surface using adhesive resins. This approach made the device ideal for use in orthodontic patients or others at higher risk for tooth decay, as it provided localized fluoride treatment. The sustained-release nature of this device marked a pioneering step in fluoride technology, helping to set the stage for future advances in fluoride delivery systems designed for long-term efficacy[6].

b) Glass Fluoride Devices (1980s):

In the 1980s, the glass fluoride device emerged as a novel innovation in fluoride delivery, particularly for orthodontic patients. These devices were designed to release fluoride slowly, helping to prevent dental decay around orthodontic brackets and wires, which are prone to plaque accumulation and can be difficult to clean properly. The glass fluoride device represented an advancement in fluoride delivery by offering a continuous release of fluoride, particularly in patients who may be at higher risk of cavities due to the presence of braces or other dental appliances.

DEVELOPMENT AND EVOLUTION OF THE GLASS FLUORIDE DEVICE:

The concept of the glass fluoride device was first introduced in 1984 by Curzon, in collaboration with the Department of Animal Physiology at Leeds University. Interestingly, this device was adapted from glass boluses—a device historically used in livestock management. These boluses were designed to gradually release trace minerals such as selenium, copper, and cobalt into animals' digestive tracts to prevent nutritional deficiencies, which are common in pasture-fed animals. Given the connection between certain trace elements and dental caries prevention, the concept of controlled release was adapted for human dental care to prevent tooth decay in orthodontic patients.

Curzon's modified version was intended to release fluoride slowly over time. The original design was dome-shaped, measuring 4 mm in diameter and 2 mm in thickness, and it was typically bonded to the buccal surface of the primary permanent molar using adhesive resins. However, one of the significant challenges of the early glass fluoride devices was retention. They were prone to dislodging, especially given the short-lived fluoride release, leading to limited efficacy over time[7].

IMPROVEMENTS AND MODIFICATIONS:

Recognizing these limitations, Curzon and colleagues at Leeds University made several modifications to improve both retention and fluoride release. The updated design was larger and more durable, with the device measuring 6 mm in length, 2.5 mm in width, and 2.3 mm in depth. These modifications resulted in a more effective fluoride release and enhanced retention, making the device much more reliable[8].

This revised glass fluoride device proved capable of releasing fluoride over a longer period, with some studies indicating it could remain effective for up to two years. According to Toumba and Curzon in 1993, the fluoride glass matrix would gradually dissolve upon exposure to moisture, providing sustained fluoride release while maintaining the structural integrity of the device. This development marked a significant improvement over previous designs, which often failed to maintain their fluoride-releasing capabilities for extended periods.

Clinical Findings and Effectiveness:

A pilot study conducted on the efficacy of slow-release glass devices reported promising results. The study monitored fluoride levels in saliva and gingival crevicular fluid over time. After three months of use, the fluoride concentration in saliva increased from 0.02 ± 0.04 ppm to 0.06 ± 0.12 ppm, and in gingival crevicular fluid, fluoride levels remained stable, with minimal variation from baseline. Importantly, the study found no adverse effects related to the use of the devices. Both the Löe Plaque Index and Gingival Index remained consistently low, suggesting that the fluoride release did not contribute to oral health issues such as plaque accumulation or gum inflammation. This further demonstrated the safety and effectiveness of fluoride glass devices in clinical practice[9].

c) <u>Fluoride-Releasing Adhesive Systems (1990s–2000s):</u>

During the 1990s, fluoride-releasing adhesive systems became more prominent. These systems incorporated fluoride into adhesive materials, which could be bonded directly to the tooth surface. This allowed for more consistent fluoride release over time. Fluoride-releasing orthodontic bands became widely used, particularly for patients with braces, as they provided targeted fluoride application in areas that are challenging to clean properly, such as around brackets and wires.

Additionally, fluoride-releasing composite resins and sealants were developed to provide long-term fluoride exposure at the site of application. These systems became an important preventive measure in orthodontics and restorative dentistry, as they helped reduce the risk of caries during orthodontic treatment[10].

RECENT ADVANCES: CONTROLLED RELEASE DEVICES AND NANO-TECHNOLOGIES:

In the past two decades, the emphasis has been on refining fluoride delivery methods to increase efficacy and patient compliance.

Hydroxyapatite-Eudragit RS100 System (2000s):

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[11]. 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[12,13].

This method holds particular promise for pediatric and preventive dentistry, as children and adolescents are often more susceptible to caries and may benefit from prolonged fluoride exposure without requiring frequent applications. In clinical trials, the hydroxyapatite-Eudragit RS100 system demonstrated efficient fluoride release and an ability to remineralize demineralized enamel effectively, showing that it could be a viable alternative to conventional fluoride varnishes or gels[14]. 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[15].

Future research could focus on optimizing this system for various age groups, particularly within pediatric populations, and evaluating its long-term efficacy in reducing caries prevalence. If successful, the hydroxyapatite-Eudragit RS100 fluoride system could become a staple in preventive dentistry, delivering consistent fluoride levels for sustainable oral health benefits.

Smart Fluoride Devices and Personalized Medicine (2010s–Present):

Recent advancements in fluoride delivery are leveraging smart technology and personalized approaches to improve dental care outcomes. Innovations in nanotechnology and biomimetic materials aim to enhance fluoride retention on enamel, enabling a more efficient remineralization process. For example, 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[16].

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. For instance, when the oral pH drops, which indicates a higher risk for demineralization, these devices can increase fluoride release to help buffer the acidic environment and protect the enamel. This on-demand fluoride release aligns with the body's natural needs, making it both efficient and potentially less toxic than constant exposure[17].

Furthermore, the development of smart fluoride systems capable of interacting with oral microbiota opens up new possibilities for personalized medicine in dentistry. By tailoring fluoride release based on individual factors—such as oral bacterial composition or specific caries risk—these systems offer a targeted preventive approach, which is especially promising for high-risk populations or those with unique oral health needs[18].

CONCLUSION:

Fluoride devices have played a pivotal role in modern preventive dentistry, helping to significantly reduce the prevalence of dental caries. From the early days of fluoride water supplementation to the development of sophisticated fluoride-releasing devices, the innovations in fluoride application continue to shape oral health care. The future promises even more targeted and personalized fluoride delivery systems, with potential breakthroughs in nano-fluorides and biomimetic technologies. As fluoride technology continues to evolve, it will likely remain a cornerstone of preventive dentistry.

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Conflicts of Interest

There are no conflicts of interest.

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