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Effects of Fluoride Use on Oral and Dental Health

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Summary

Fluoride has been recognized since the 20th century as one of the most important agents with proven efficacy in preventing dental caries. Dental caries, regardless of the diverse socioeconomic or sociocultural characteristics of countries, emerges as a common public health concern. Research has demonstrated that fluoride prevents the demineralization of teeth against acids derived either from dietary sources or produced by cariogenic bacteria such as Streptococcus mutans. Moreover, fluoride may promote the remineralization of early enamel carious white spot lesions and exert antimicrobial effects by disrupting the mechanisms of cariogenic bacteria. For this reason, in combating dental caries, fluoride has been employed both systemically, such as through water fluoridation, and topically, through methods applied by dental professionals such as fluoride gels. In addition to professional applications, fluoride has also gained widespread use at the community level through individual hygiene and care practices, including fluoridated toothpastes and mouth rinses. The aim of this article is to provide essential knowledge that contributes to health literacy regarding fluoride use, and to present a review on its current applications in dentistry, its mechanisms of caries prevention on dental tissues, and its potential adverse effects.

Keywords: Dental decay, Fluoride, Public health, Dental public health, Preventive dental care

Özet

Flor 20. yüzyıldan itibaren çürük önleyici etkinliği kanıtlanmış ve bu amaçla kullanılan en önemli malzemelerin başında gelmektedir. Diş çürüğü ise ülkelerin farklı sosyoekonomik veya sosyokültürel özelliklerine bakmaksızın ortak bir halk sağlığı sorunu olarak öne çıkmaktadır. Araştırmalar göstermiştir ki, flor dişlerin yiyecekler yoluyla alınan veya ağızdaki Streptococcus mutans gibi çürük yapıcı bakteriler tarafından oluşturulan asitlere karşı dişin demineralize olmasını (mineral kaybını) önler, başlangıç aşamasındaki mine çürüğü olan beyaz lezyonların (white spot lessions) geri dönüşümünü (remineralizasyonu) sağlayabilir ve çürük yapıcı bakterilerin etki mekanizmasını bozarak antimikrobiyal etki gösterebilir. Bu sebeple, dünya hastalık yükünde önemli bir yere sahip olan diş çürüğü ile mücadelede flor gerek suların florlanması gibi sistemik yollarla gerekse diş hekimleri tarafından uygulanan flor jeli gibi yöntemlerle, özellikle henüz dişleri yapım aşamasında olan çocuklara yönelik, önemli bir ağız ve diş sağlığı koruyucu uygulaması olarak kullanılmaktadır. Profesyonel uygulamaların yanı sıra florlu diş macunları, florlu ağız gargaraları ile flor, bireysel hijyen ve bakım alışkanlıkları yoluyla da toplum nezdinde yaygın kullanım alanı bulmuştur. Bu makalenin amacı, flor kullanımı konusunda sağlık okur yazarlığına katkı sağlayacak önemli bilgileri paylaşmak ve florun günümüz diş hekimliğinde kullanım yöntemleri, diş üzerinde çürük önleyici etki mekanizması ve muhtemel yan etkileri konusunda bir derleme sunmaktır.

Anahtar Kelimeler: Diş çürüğü, Flor, Halk sağlığı, Toplum ağız diş sağlığı, koruyucu diş hekimliği

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Introduction

Fluorine (F), the most reactive and electronegative element in the periodic table, belongs to the halogen family. Due to its extreme reactivity, it is found in nature in the form of compounds, creating fluoride salts (fluorides) with all metals (6,9). Although fluoride began to be incorporated into oral care products in the 1950s, human exposure to fluorine had already occurred earlier through the consumption of fluoride-containing foods and beverages such as tea, tobacco, seafood, and drinking water (5).

In the early 20th century, Dr. Frederick McKay in Colorado, United States, and Dr. J.M. Eager in Italy observed that fluoride present in regional water supplies could cause brown discoloration of teeth, a condition noted in up to 90% of local children (1,2). Meanwhile, McKay together with dentist Greene Vardiman Black also hypothesized that teeth exposed to fluoride were more resistant to dental caries (1). Subsequent research confirmed that controlled use of fluoride is an effective method for preserving dental health and preventing caries (3,4,7,17).

To harness its anticariogenic properties, systemic fluoride intake has been promoted through the fluoridation of community water, milk, and salt. Meanwhile, topical applications such as solutions, gels, mouth rinses, toothpastes, and dental restorative materials have become the most used forms of fluoride in modern preventive dentistry (7).

Dental Caries and Its Formation Mechanism

According to the World Health Organization (WHO), dental caries affects approximately 3.7 billion people worldwide, and untreated caries in permanent teeth was reported as the most prevalent health condition in the Global Burden of Disease Report 2021 (25). In Türkiye, oral and dental health problems rank as the fifth most common condition in the 0–6 age group and the third most common in the 7–14 age group, following upper respiratory tract infections and diarrhea (32).

Dental caries is a bacterially induced process that is nourished by carbohydrate intake and can be modified through oral hygiene and cleaning practices (10). Enamel, the outermost layer of teeth and the hardest tissue of the human body, is composed of approximately 97% inorganic minerals. When exposed to acids produced by dental plaque bacteria, enamel begins to lose its minerals, resulting in demineralization. The acid-producing capacity of cariogenic bacteria such as Streptococcus mutans, Lactobacillus, Actinomyces, and Bifidobacterium increases with the frequent consumption of carbohydrates and sugary foods/beverages. The initial visible manifestation of this process is the appearance of white spot lesions representing localized demineralized areas (10,11).

These white spot lesions are reversible in the early stages; however, if the process continues, they expand across larger enamel surfaces and progress toward the underlying dentin, leading to more darkly pigmented lesions. This stage, referred to as dentin caries, progresses more rapidly than enamel caries due to the lower mineral content and reduced hardness of dentin. While incipient enamel lesions can be remineralized and reversed, dentin caries is irreversible once it develops, although its progression can be halted with appropriate preventive measures (32).

Mechanism of Action of Fluoride

Fluoride, the most frequently used agent in caries prevention, protects tooth structures through three principal mechanisms: preventing demineralization, promoting remineralization by replacing lost minerals, and inhibiting the growth and organization of cariogenic bacteria (7,8,9,12).

The natural structural units of teeth, hydroxyapatite crystals, transform into fluorapatite crystals in the presence of fluoride ions. Fluorapatite crystals are more resistant to demineralization in acidic environments (11). Thus, fluoride reduces demineralization by preventing mineral loss and reinforcing weakened enamel through deposition of fluorapatite. This is considered the primary anticariogenic mechanism of fluoride (9).

The demineralization process can be reversed through remineralization, provided salivary pH is neutralized and sufficient calcium and phosphate ions are available (27). Fluoride plays a catalytic role in enhancing the activity of calcium and phosphate ions, thereby facilitating remineralization of tooth surfaces (28).

Fluoride also disrupts bacterial communication pathways, prevents their organized activity as biofilms, and alters the oral microbial ecology by reducing the proportion of cariogenic bacteria. Fluoride, which reduces the surface energy of the tooth, prevents bacteria from adhering to the tooth surface and reduces the rate of decay-causing (cariogenic) bacteria in the oral environment in favor of other bacteria. One of the important effects of

fluoride on bacterial metabolism is that it reduces the acid and extracellular matrix production of bacteria by inhibiting enzymes such as enolase and urease (11, 12).

Table 1. Mechanism Of Action of Fluoride (5,8)

1. Strengthening tooth enamel against acid solubility	2.Reminalization	3. Antibacterial effects
•Forms fluorapatite crystals •Forms a protective calsium fluoride layer	•Prevents demineralization of tooth enamel •Compansates for mineral loss of tooth enamel	•Inhibits bacterial enzymes •Reduces the surface energy of the tooth •Removes bacteria from the hydroxyapatit structure

Fluoride Applications as Protective Methods for Oral and Dental Health

Systemic Fluoride Applications

Systemic absorption of fluoride particularly affects unerupted teeth. Thus, teeth, which have a higher mineral content during tooth formation, become more resistant to dental caries after eruption (13, 24).

Water Fluoridation

The subsequent addition of naturally occurring fluoride to drinking water sources, where it is not present in caries-preventive concentrations, is an effective, inexpensive, and easy-to-implement preventive public health method in combating tooth decay and has been cited as one of the ten most important public health achievements of the 20th century (18, 26).

The recommended daily intake of fluoride in drinking water has been set at 1 ppm (52.6 µmol ml−1), with 0.7–1.2 ppm considered acceptable (11). However, since individual fluoride intake varies from person to person and the risk of overdose arises, water fluoridation has become a more cautious approach.

Milk Fluoridation

Adding fluoride to milk has been tested to ensure that school-aged children benefit from the tooth-protective effects of fluoride. This method, recommended in regions with low levels of fluoride in drinking water, is a public health practice requiring stronger evidence for its caries prevention (18).

Salt Fluoridation

Salt, one of the most widely consumed substances in society, has been sought to benefit from its widespread use, and the addition of fluoride to salt has been considered. However, this practice is no longer recommended because excessive salt consumption can have detrimental health effects.

Fluoride Tablets

Fluoride can be given in tablet form to individuals who are thought to be unable to obtain sufficient fluoride through water or individual applications. Using small, age-appropriate doses, swishing it around in the mouth without swallowing, dividing it into small doses rather than all at once, and spreading it throughout the day provides both systemic and topical benefits of fluoride tablets. Fluoride tablets should be used with caution, especially during the first three years of life (see Table 1). Studies have shown that while fluoride has a weak effect on primary teeth, its effect on permanent teeth is strong. On the other hand, the use of fluoride supplements up to age six, especially in the first three years, significantly increases the risk of fluorosis (31).

Table 2. Systemic Fluoride Intake Recommendations

Age	Fluoride Level of Water		
	< 0. 3 ppm F	0.3 - 0,6 ppm F	>0.6 PPM F
0- 6 months	0	0	0
6 months- 3 years	0.25 mg	0	0
3– 6 years	0.50 mg	mg	0
>6 years	1 mg	0.50 mg	0

Topical Fluoride Applications

Topical fluoride applications can be applied professionally by dentists via fluoride gel, solution, or varnish, or individually using fluoride containing dentifrices such as toothpaste, fluoride mouth rinses or floss. Professional topical fluoride applications, which are more costly than systemic fluoride applications, require more time, motivation, and individual effort, and their sustainability in individuals at high caries risk is questionable (10). However, topical fluoride applications have been found to be more effective than systemic fluoride intake in preventing tooth decay (13, 24). Furthermore, fluoride appears to be a more effective anti-caries agent when applied at different times throughout the day. Therefore, the use of toothpaste and mouthwash at regular intervals is important (32).

The individual's caries risk should be assessed before professional topical fluoride application for caries prevention (13, 14). While fluoride application is not necessary for individuals at low caries risk, topical fluoride application is recommended every six months for individuals at moderate risk and every three months for individuals at high caries risk (13, 14).

Topical fluoride application allows fluoride to remain in the mouth for a longer period, acting as a reservoir, and is incorporated into the enamel structure as calcium fluoride (CaF_2), which protects the tooth against mineral loss. This makes the tooth more resistant to acid attacks and demineralization (mineral loss), while increasing its ability to remineralize (13).

Professional Topical Fluoride Applications

Fluoride Solutions and Gels

Fluoride gels have replaced the previously commonly used fluoride solutions. Fluoride varnishes, on the other hand, are preferred, especially in young children, due to their fluidity, ease of application, and minimal risk of swallowing (14). In a study comparing Silver Diamine Fluoride (SDF) gel and Sodium Fluoride varnish, Fathima and Govindaraju found that over a 12-month period, fluoride gel prevented caries progression by 66.7%, while fluoride varnish was 70.5% effective in the same situation (30). Initially used in the form of NaF, gels are now also applied with APF (acidified phosphate fluoride) and SnF2 (stannous fluoride) contents.

Fluoride Varnishes

Fluoride varnishes, which have a less fluid texture than fluoride gels, dry easily after application and do not cause the need to spit. Therefore, they are ideal for younger children or those with a gag reflex. With fluoride varnishes, teeth are kept in contact with fluoride for 12 hours or longer (14). Waluya et al. found that in vitro fluoride varnish significantly increased the hardness of enamel (from 174 to 270 on the Vickers Hardness Scale) within seven days (28). It has also been shown that demineralization and white spot lesions, which are frequently seen in patients wearing orthodontic braces due to difficulty maintaining oral hygiene, can be prevented with fluoride varnish (29).

Iontophoresis

Iontophoresis is a non-invasive technique that utilizes electric current to more effectively penetrate the tooth. Fluoride is released deeper than traditional methods, which also increases tissue penetration (20).

Individual Topical Fluoride Applications

Fluoride Toothpaste

Fluoride toothpastes, the most used method in daily oral and dental health practices, can have varying amounts of fluoride content. Generally, toothpastes containing 1500 ppm of fluoride are considered high-fluoride, while those containing 500 ppm or less are classified as low-fluoride toothpaste (21). In a review of 74 trials involving 42,300 children, Marinho et al. reported that fluoride toothpastes effectively prevented tooth decay compared to placebo toothpastes. This effect was more pronounced in children with existing decay (21).

Fluoride Mouthwashes

Mouthwashes are recommended oral care products for use in addition to tooth brushing (22). Rinsing with a fluoride mouthwash after using fluoride toothpaste has been shown to be more effective in remineralizing lesions at the initial stage of caries than using toothpaste alone (23).

Fluoride Side Effects

While fluoride applications are effective in preventing tooth decay, they have various side effects that can develop depending on the dose, duration of use, and the age of the user. Fluoride can cause side effects that can lead to death in the form of acute or chronic poisoning. The toxic dose that causes early signs of poisoning

is 1 mgF/kg body weight, the probable toxic dose is 5 mgF/kg, and the safely tolerated dose is estimated to be 8 mgF/kg (35). In children, the toxic dose of fluoride has been found to be 0.1-0.3 mg/kg, the minimum lethal dose is 5 mg/kg, and the lethal dose is 15 mg/kg. It has been determined that most fluoride's toxic effects are caused by children accidentally swallowing toothpaste (37).

Acute fluoride poisoning can manifest with symptoms such as abdominal pain, vomiting, and black stools. Chronic fluoride poisoning, on the other hand, can cause pathological changes in the heart, kidneys, and skeletal structure, negatively impacting the entire body (34). The earliest and most obvious sign of fluoride's chronic toxicity is fluorosis (37). Fluorosis is a condition characterized by yellow-brownish staining on teeth resulting from the ingestion of high doses of fluoride (drinking water containing fluoride concentrations greater than 1 ppm) during the period when tooth enamel is forming and maturing (between the ages of 0 and 4) (13). While normal enamel is smooth, shiny, creamy-white, and translucent, in the early stages of fluorosis, a few white spots or spots begin to appear. Depending on the severity of fluorosis, white opaque spots increase, and brown spots gradually become visible on the teeth. In severe cases of fluorosis, the entire tooth surface is covered with permanent brown discoloration in the form of stains or cavities (34).

The limited therapeutic dose range of fluoride has also sparked controversy regarding its potential side effects. In a cohort study conducted in Florida, where the city's water supply is fluoridated, researchers claimed that although the incidence of tooth decay decreased with increased fluoride exposure, there was an increase in the number of neurodevelopmental disorders such as autism, intellectual disability, attention deficit hyperactivity disorder (36). United States Secretary of Health Robert F. Kennedy Jr. defined fluoride as "Fluoride is an industrial waste associated with arthritis, bone fractures, bone cancer, IQ loss, neurodevelopmental disorders, and thyroid disease " and stated that they would remove fluoride from public water in the United States (38). Ergin and Eden claim that studies investigating the relationship between fluoride use and IQ test scores conducted in China and India should not be taken into account because they found them insufficient to evaluate other factors that could affect IQ test results. (39). On the other hand, a meta-analysis by Taylor et al. revealed that IQ scores decrease as fluoride exposure increases, but there is insufficient data and uncertainty regarding the effect of doses lower than 1.5 mg/L on IQ scores (40).

Conclusion

Fluoride, its caries-preventing effects have been known for many years, stands out as the most widely used caries-preventive agent today. Fluoride can be administered systemically through water fluoridation or tablets, or topically as an oral and dental protective agent through solutions, gels, and varnish applications. Since fluoride has a narrow therapeutic dose range, it has been noted that total fluoride intake through various routes can lead to acute fluoride poisoning or fluoride toxicity. While some argue that fluoride is the most effective anti-caries agent in preventing tooth decay, others consider it a chemical harmful to human health. People who, particularly among social media users, attempt to highlight the cumulative effects of high and continuous fluoride intake as a side effect of all fluoride oral and dental care products, and who generally agree on issues such as anti-vaccine behaviour, are attempting to influence public opinion on this issue. In this regard, adequate health literacy regarding preventative oral and dental health practices will help individuals shape their health-seeking and consumption habits in the most appropriate way.

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