Chapter

The Application of Fluoride in Dental Caries

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Abstract

The most efficient way to prevent caries is by using fluoridated dental products. Fluoride can reduce enamel demineralization and promote enamel remineralization. In terms of prevention, the topical application of fluoride is accessible, which includes fluoride toothpaste, fluoride varnish, fluoride gel, and mouth rinse. Besides, the application of fluoride is systematical. In some countries, fluoride is added into water, salt, or milk. Fluoride is also used for the medical treatment of early dental caries. However, fluoride is a double-edged sword. Excessive fluoride intake will cause toxic reactions, and dental fluorosis is caused by a high intake of fluorides during tooth development.

Keywords: fluoride intake, caries prevention, fluorosis, fluoride application

1. Introduction

Fluorides are regarded as effective materials in the control of dental caries, which can both benefit the prevention and treatment.

Fluoride is widely distributed in nature and is present in all soils, water, plants, and animals [1]. Water-soluble fluoride in the soil is the most valuable for organisms. Because fluoride is not distributed in soil evenly, the concentration of fluoride in water is different in different areas. Plants generally contain a certain amount of fluoride, which is absorbed from the soil and water. Besides, plants can increase the content of fluoride by absorbing deposited fluoride on the leaves or absorbing the fluoride in the atmosphere directly. Fluoride in the atmosphere mainly comes from a volcanic eruption, industrial waste gas, and coal combustion [2, 3].

2. Fluoride: intake and mechanism

Most of the human fluoride comes from food and water [1]. The primary source of human fluoride is water. It is easy for the body to absorb fluoride from water. However, the amount of fluoride absorbed by the body from drinking water is directly controlled by the fluoride concentration and the amount of drinking water. The amount of drinking water depends on age, living habits, local temperature, and other factors. Adults drink about 2500–3000 ml of water per day. The second source of human fluoride is food. All foods, including plant or animal food, contain a certain amount of fluoride, but the content of fluoride among them is widely different. Plant food, such as grains, vegetables, fruits, and so on, often has significant differences in fluoride content due to different regions. The fluoride in the air is not the primary source of human fluoride. Unfortunately, under some special environmental conditions, air can be polluted by fluoride. In this way, the fluoride in the air can enter into the human body through the respiratory tract, causing fluorosis. In addition, there are other possible sources of fluoride. For example, some oral topical fluoride products have very high fluoride concentration. If they are used unproperly without the guidance of doctors, it may lead to an increase in fluoride intake. The total intake of fluoride is the sum of the intake of fluoride from the air, water, diet, and so on. It contains two meanings: one is the total adaptive intake, which refers to the physiological demand for preventing and maintaining normal biological functions of the body; the other is the total safe intake, which refers to the maximum amount that the body needs. When the body takes more chemicals than the safe intake for a long time, it will lead to chronic poisoning. It isn't very easy to unify the standard of appropriate intake and safe intake of fluorine, so we recommend the proper daily intake of fluorine is 0.05–0.07 mg [4].

At present, it is believed that the primary mechanism of fluoride to prevent caries is by reducing demineralization and promoting enamel remineralization. Besides, fluoride has effects on the microorganism.

Under normal conditions, the solubility of enamel in acid buffer varies according to the concentration of fluoride. When the concentration of fluoride reaches 0.05 mg/l, the solubility of enamel will be reduced. Fluorine can be combined with free hydroxyapatite (HA) to form fluorohydroxyapatite (FHA) in the saturated solution of hydroxyapatite, which can be redeposited in enamel. And this process is named remineralization. In contrast, when the hydroxyapatite in the solution is not saturated, fluorine can directly enter the crystal to form FHA or exchange with hydroxyl ion in enamel to form fluorapatite (FA). When the teeth are eroded by acid, the pH value decreases, and the teeth demineralize. At the same time, calcium fluoride dissolves and releases fluoride and calcium ions into saliva. When the calcium and phosphorus ions in saliva are saturated, they will make the minerals return to the teeth. If this process happens on the surface of the demineralized crystal, a new crystal surface will be formed.

In addition to preventing caries, dentists also use fluoride to treat dental caries [5]. The fluoride deposited on the surface of demineralized enamel can promote the remineralization of enamel and then play a role in treating dental caries. There are lots of fluorides reported to be used in the treatment of dental caries, mostly in the early stage of tooth decay, such as sodium fluoride (NaF) and silver diamine fluoride (SDF) [6]. A system review concluded that applying 38% SDF annually to older adults who had exposed root surfaces decreased the prevalence of new root carious lesions by at least 50% [7].

3. Toxic effects and fluorosis

High intake of fluoride may increase the risk of acute and chronic fluoride toxicity, fluorosis, and other systemic diseases. Some studies focus on the molecular mechanisms associated with fluoride toxicity. These studies have demonstrated that fluoride can induce oxidative stress, regulate intracellular redox homeostasis, lead to mitochondrial damage and endoplasmic reticulum stress, and alter gene expression [1, 2].

3.1 Acute toxicity

Taking a large amount of fluoride by mistake at one time can cause acute fluoride toxicity. The main symptoms are nausea, vomiting, diarrhea, and even intestinal bleeding. The serious ones cause organic damage, such as the heart, liver, and kidney, resulting in a coma. Patients usually die or recover within 4 h. It is a critical period; however it is very short. The principles of emergency treatment are emetic, gastric lavage, taking calcium orally or intravenously, sugar supplement, liquid supplement, and symptomatic treatment.

3.2 Chronic toxicity

Chronic fluoride toxicity can be caused by long-term excessive intake of fluoride. According to the different sources of fluoride, chronic fluoride toxicity can be divided into endemic fluorosis and industrial fluorosis. Firstly, endemic fluorosis is a kind of disease that occurs in a specific geographical environment. It is a chronic systemic accumulation of fluorosis caused by excessive intake of fluoride through water, air, or food. Drinking water with high concentration of fluoride and living with domestic coal pollution both may cause endemic fluorosis [8]. The degree of damage to the body mainly depends on the dose of fluoride. There is no significant difference in the effect of fluoride from different sources on the body. Secondly, industrial fluorosis usually exists in workers who work with cryolite and bauxite for a long time. They may intake excessive fluoride by eating, drinking, or breathing. The main clinical manifestations of chronic toxicity are dental fluorosis and skeletal fluorosis. Because dental fluorosis is manifested early in the cases of fluoride toxicity, dental fluorosis can be used as a biomarker of fluoride toxicity. Chronic exposure to excessive fluoride is associated with children's dental health and intelligence scores. A study found that dental fluorosis is positively related to the loss of high intelligence [9]. When it comes to how to prevent chronic fluorosis, there are three methods. First, the control of the concentration of fluoride in water. Water fluoridation is an effective way to prevent caries. However, the fluoride concentration should be monitored in case of dental fluorosis. As for those areas where the water has high content, it is necessary to take methods to remove fluoride from the water. Secondly, eliminate domestic coal pollution as much as possible. Last, the prevention of industrial fluoride pollution.

3.3 Dental fluorosis

Dental fluorosis is an excessive intake of fluoride during the mineralization period of tooth development. It is the most common sign of local chronic fluorosis, and it can be found early and quickly. Its clinical manifestations are as follows: (1) there are white strips on the surface of enamel, and the strips can fuse to form patches, even spread to the whole surface. (2) Some of the strips or plaques are yellowish or brown. (3) In severe cases, there is an enamel defect or tooth defect because of dental fluorosis.

Dental fluorosis mostly occurs in permanent teeth while less in primary teeth, because it is difficult for the fluoride to pass through the fetal blood barrier. The amount of teeth involved in dental fluorosis is related to the length of time living in the high-fluoride area during the tooth mineralization period. If a child moves in the high-fluoride zone after the age of 6–7, dental fluorosis almost does not appear. The severity of dental fluorosis depends on the degree of excessive intake of fluoride. If fluoride is severely excessive, the structure of enamel is disordered, and the tooth tends to stain or collapse. The principal reason of abnormal mineralization in dental fluorosis may be related to that high concentration of fluoride that can inhibit the activity of alkaline phosphatase, which is essential to bone and tooth formation.

The primary source of excessive fluoride intake is water fluoride [10]. Therefore, the principle of preventing dental fluorosis is avoiding absorbing excessive fluoride from water during the tooth mineralization period.

Some non-fluoride factors also may contribute to dental fluorosis. A research [11] discusses the effect of elemental contents on the risk of dental fluorosis, and it reported that high levels of F, Al, As, Pb, and Cr and low levels of Se, Zn, Cu, B, Ca, and P increase the risk of dental fluorosis. It suggests that taking measures to decrease the contents of F, Al, As, Pb, and Cr in the environment and increase the contents of Se, Zn, Cu, B, Ca, and P at the same time are useful for the control of fluorosis.

In addition, gene is regarded as a relevant risk factor of dental fluorosis [12]. Increasing evidence shows that an individual's genetic background could increase the risk of fluorosis when other factors like fluoride exposure remain the same [13]. A cross-sectional study [14] in Mexican children revealed an association of rs 412777 polymorphism in the COL1A2 gene with dental fluorosis. MMP20 was supposed to be related to the various phenotypes of dental fluorosis and may serve as a protective marker [15]. These would provide some evidence for identifying those people who are at risk of developing dental fluorosis in their later lives.

At the same time, we should pay attention to distinguishing dental fluorosis from enamel hypoplasia. Enamel hypoplasia usually has clear boundary strips and exists in one or more teeth. On the contrary, the strips of dental fluorosis have no definite boundary. The symptom regularly appears in several teeth, and patients often have a history of living in the high-fluoride area.

When it comes to how to treat dental fluorosis, bleaching and resin infiltration treatment both work for mild dental fluorosis [16]. However, for severe dental fluorosis, a full crown prosthesis is a better choice. A porcelain veneer is also used in severe cases [17]. Recently, some clinic studies discuss the effect of at-home bleaching and consider it effective and efficient [18]. Microabrasion is another hot topic. When removing the abnormal enamel affected by fluoride, it is necessary to protect the healthy tooth tissue as much as possible. Microabrasion not only can protect the healthy tooth tissue but also can achieve the aim of treating dental fluorosis [19].

3.4 Skeletal fluorosis

However, skeletal fluorosis may lead to the impairment of muscle movement, calcification of ligaments, increased osteosclerosis, and cancellous bone formation in the advanced stage. What's more, it may lead to the limitation of joint movement, muscle atrophy, and deformity of bone, spine, and major joints [2, 20].

4. Systemic use of fluoride

The correct way to use fluoride is that the body ingests fluoride through the digestive tract and passes through the gastrointestinal tract. The fluoride is absorbed into the blood circulation and then transferred to the tissues such as teeth and saliva to prevent caries. There are four main methods in the systemic use of fluoride, which are water fluoridation, salt fluoridation, milk fluoridation, and fluoride tablet.

4.1 Water fluoridation

Water fluoridation refers to adjusting the concentration of fluoride in water to appropriate level to prevent caries without causing the prevalence of dental fluorosis. Nowadays, water fluoridation is accepted by more than 150 science and health organization, such as the World Health Organization (WHO) and the International Association for Dental Research (IADR) [4, 10, 21]. In 1958, Singapore was the first country in Asia to carry out water fluoridation, which covers 100% of its population. It does contribute to improving the level of oral health in Singapore [22]. Some researchers assessed disability-adjusted life years (DALYs) and DALY rate due to dental caries preventable through water fluoridation in Iran, and they found that in 2016 DALYs were 14,971 (95% uncertainty interval 7348–24,725) and DALY rate was 18.73 (9.19–30.93) [23]. The results indicated that water fluoridation plays an important role in dental public health at the national level. According to the WHO's recommendation, the allowed fluoride level in water is 1.5 mg/L.

4.2 Salt fluoridation

Unlike water fluoridation, the carrier of salt fluoridation is salt. Fluoride is added into salt and is absorbed into the body by eating salt. It is reported the salt fluoridation was used in a dental research project in Colombia [24], and now it is extended into more than 20 countries [4]. Although salt fluoridation is not as popular as water fluoridation, it is still a supplement to water fluoridation, especially in the low-fluoride area and no tap water area. The dietary habit is different in different countries; therefore, the amount of salt intake in different countries is different. Thus, the content of added fluoride ought to depend on specific conditions.

Although salt fluoridation is not restricted by water service, the most disadvantaged point of this method is that the fluoride content is precisely hard to control. If someone prefers to eat salty, it is more likely for him/her to get dental fluorosis, which causes caries. What's more, considering that few citizens know about how much fluoride was added into salt, the government participating in water fluoride is a better choice.

4.3 Milk fluoridation

Milk fluoridation is another way to use fluoride, which means the fluoride is added into milk or milk powder. However, it has the same shortcoming as salt fluoridation—difficult to control. Milk is considered containing nutrients that help to buffer acid, and it may reduce the risk of dental caries after exposure to a sugar beverage. A research studied the effect of rinsing with water, non-fluoridated milk, and fluoridated milk on acidic dental plaque, the results showed that rinsing with fluoridated milk increased the pH value of acidic plaque to the resting level faster [25]. Considering the safety of using fluoride, the intake of fluoride should be controlled strictly. Therefore, the propaganda and education of milk fluoridation are important.

4.4 Fluoride tablet

Fluoride tablet is a supplementary method of systemic application of fluoride for children, especially for the children who live in the area with low content of fluoride, and when the government does not carry out water fluoridation policy. Fluoride tablet must be used under dentists' recommendations and teachers' or parents' supervision. A study assessed adherence to oral fluoride and barriers to adherence in a community without water fluoridation, and more than half of parents were found that they either had not or did not know whether their children had received fluoride on the day before. What's more, adherence to fluoride tablets in the primary care setting is low [26]. If possible, choosing water fluoridation as a systemic fluoride application method is a better choice.

5. Topical application of fluoride

The topical way to use fluoride is to apply fluoride directly to the surface of the tooth. It is a double-edged sword. On the one hand, this method can increase the topical concentration of fluoride quickly and make fluoride play a better role in prevention and treatment. At the same time, topical use is a supplement to the systemic use of fluoride. The combination of these two methods will enhance the effect of fluoride. On the other hand, higher topical fluoride concentration may cause toxic effects, such as dental fluorosis. And fluoride can enter the digestive tract through the oral cavity, and then it will be absorbed into the blood, resulting in toxic effects.

However, if we use fluoride in the right way, we can avoid the toxic effects of fluoride almost completely. So, it is important to know how to use fluoride in a correct way.

The common ways to use fluoride topically are through fluoride toothpaste, fluoride mouth rinse, fluoride varnish, fluoride gel, and fluoride foam. They will be explained separately.

5.1 Fluoride toothpaste

There are many different types of toothpastes on the market that are applied to prevent caries and improve oral health. Around 90% of these contain fluoride, a mineral found in relatively low concentrations in fresh and seawater. Fluoride toothpaste by far provides a higher level of the mineral than any other source. It is a cheap and convenient way to promote dental health, which is recognized by the Centers for Disease Control and Prevention to be "one of 10 great public health achievements of the 20th century."

There are different kinds of fluoride toothpaste, such as sodium fluoride toothpaste and stannous fluoride toothpaste. It is generally believed that fluoride toothpaste has a noticeable effect on caries prevention [27, 28].

5.1.1 Sodium fluoride toothpaste

It is crucial to keep the activity of fluoride ion in sodium fluoride toothpaste. In the earlier year, due to the incompatibility of sodium fluoride with calcium carbonate, calcium phosphate, and other friction agents in toothpaste, the fluoride ion lost its activity, and the prevention effect was not evident [29]. However, after the reasonable selection of friction agents, such as acrylic plastic, calcium pyrophosphate, or silica, it is proven that the control effect is positive. Nowadays, sodium fluoride toothpaste is popular, and it does not have the defect of staining teeth.

5.1.2 Stannous fluoride

Stannous fluoride toothpaste can not only prevent caries but also provide antibacterial function and provide relief from dentin hypersensitivity [30]. The researchers studied the action mode of stannous and sodium fluoride toothpaste on anti-biofilm properties. The results revealed that stannous fluoride toothpaste had a better antibacterial effect on microbial biofilm. And stannous fluoride toothpaste was able to regulate microbial composition within a multi-species biofilm [31]. However, long-term use of stannous fluoride toothpaste could lead to tooth staining [32]. The tooth discoloration caused by stannous fluoride is due to the reaction of the tooth with the tin ion present in the formulation. And stannous ion may also cause the toothpaste to taste bad. At the same time, the stannous ion easily loses its activity in toothpaste.

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Recently, researchers try to find a new formula. First of all, the composite chelating technology can stabilize the stannous ion in the toothpaste effectively during the storage and transportation processes. Moreover, the stannous ion still can be released rapidly during the brushing process. Meanwhile, the stannous ion is stabilized by the composite chelating technology to resist the staining problem of stannous fluoride. It was reported that the addition of zinc phosphate could significantly improve the stability of stannous ion more effectively than other stabilization methods [33].

Besides, researchers are looking for more effective fluoride toothpaste to prevent caries. A study showed that the incorporation of 2% arginine in sodium fluoride toothpaste significantly increased the remineralization of enamel caries-like lesion when compared to sodium fluoride toothpaste [34].

5.2 Fluoride mouth rinse

When fluoride is added into mouth rinse, we call it fluoride mouth rinse. Although mouth rinse only stays in the oral cavity for a short time, it is still considered as having an effect on the prevention of caries. As reported, the combined use of fluoride toothpaste and mouth rinse shows better results than the use of either alone [35]. The most commonly used fluoride mouth rinse is sodium fluoride mouth rinse. Fluoride mouth rinse is suitable for those people who have a high risk of dental caries, who are in orthodontic treatment with a fixed appliance, or who can't take care of themselves. Because of its advantages, like low price, easy to master, and convenient to use, it is an excellent choice for school-age children. It is also necessary to read the instruction on how to use mouth rinse carefully, especially when children use it. The dose of fluoride should be controlled strictly, and mouth rinse could not be drunk. So the compliance of children needs to be taken into account.

5.3 Fluoride varnish

Fluoride varnish has a higher fluoride concentration than fluoride toothpaste and fluoride mouth rinse. It can be more durable on the surface of the tooth. There are more than 30 fluoride varnish products on the market today, most of which could be classified into 2.26% fluoride and 0.1% fluoride varnish categories [28]. It should be used with dentists' professional judgment and applied in a dental clinic or hospital. After the curing of fluoride varnish, the tooth will discolor temporarily, but brushing the tooth will make tooth return to previous color.

5.4 Fluoride gel and fluoride foam

Fluoride gel and fluoride foam both have a higher content of fluoride. Acidulated phosphate fluoride (APF) gel or foam is a universal fluoride gel or foam. As for fluoride gel, it contains many kinds of gels with different fluoride concentrations. Some of them are allowed to be used by individuals, but others should be used by professionals. The operation method shall be in accordance with the direction. Fluoride foam can inhibit the formation of caries. Therefore, the dose of fluoride foam is much less than the same effective concentration fluoride gel.

5.5 Recommendations for professional topical fluoride application

Whether using topical fluoride or not should be judged by professionals. And individual patient's preferences should also be taken into account.

According to the recommendations provided by the American Dental Association (ADA) [28], people who are at risk of developing dental caries could take the following topical fluorides: fluoride varnish, fluoride gel, fluoride mouth rinse, and fluoride toothpaste. 2.26% fluoride varnish was recommended for people older than 6 years for both coronal and root caries. Some studies showed that there was no benefit of 0.1% fluoride varnish application in children younger than 6 years. The ADA only recommended 2.26% fluoride varnish for children younger than 6 years because of the low risk of caries, although other topical fluorides may have some evidence of a benefit. As for fluoride gel, 1.23% fluoride (acidulated phosphate fluoride) gel was confirmed beneficial to younger than 6 and 6–18 age groups. It could also produce an effect on adult root caries prevention. However, the potential harm associated with swallowing APF gel could outweigh these benefits. That is why 1.23% fluoride gel was not recommended for children younger than 6 years. When it comes to fluoride foam, it shouldn't be applied to children under 6 years, and the reason is the same as the fluoride gel. There was a kind of prescription-strength, home-use gel mentioned in ADA's recommendations, which was 0.5% fluoride gel. Researchers judged that the benefits of fluoride gel in older than 6 age groups outweighed potential harm. Prescription-strength, home-use mouth rinse contains 0.09% fluoride, and its benefit outweighs the potential harm. In conclusion, 2.26% fluoride varnish or 1.23% fluoride gel or a prescription-strength, home-use 0.5% fluoride gel or 0.09% fluoride mouth rinse is all recommended for patients 6 years or older. Only 2.26% fluoride varnish is recommended for children younger than 6 years.

5.6 Recommendations of topical fluoride application for different ages

People of different caries risk levels need different caries prevention methods [27]. Children under the age of 6 years who have any incipient or cavitated primary or secondary carious lesion during the last 3 years or have a suboptimal fluoride exposure or xerostomia should be classified as having a high risk of caries. Socioeconomic status can also be an essential factor. In terms of anyone older than 6 years, the standard of caries amount is expanded to three or more incipient or cavitated primary or secondary carious lesions in the last 3 years. No incipient or cavitated primary or secondary carious lesions during the previous 3 years and no factors that may increase caries risk (see Appendix for details) are a standard of low caries risk for any ages.

Generally, fluoride toothpaste is recommended for almost everyone. However, it should be noticed that children need a lower dose of fluoride toothpaste [36].

5.6.1 Younger than 6 years

Low-risk patients in this group may receive no benefit from topical fluoride application. Fluoride toothpaste may provide them adequate prevention. High-risk patients should receive fluoride varnish applications at 3- to 6-month intervals.

5.6.2 Six to 18 years of age

Low-risk patients do not need professional topical fluoride application. Higher-risk patients should receive fluoride varnish or gel application at 6-month intervals. Fluoride varnish applications every 3 months or fluoride gels every 3 months may provide additional caries prevention benefit.

5.6.3 Older than 18 years

For lower-risk patients, whether to apply topical fluoride or not is a decision that should balance the consideration with the professional judgment and the individual patient's preferences. Higher-risk patients should receive fluoride varnish or gel applications each 3–6 months.

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As for fluoride foam, it is commonly used in practice. The evidence of its effectiveness is not as strong as the fluoride gel and varnish. But it does provide the benefit of lower fluoride dose than fluoride gel.

Conflict of interest

The authors declare no conflict of interest.

Appendix

According to the recommendations of the American Dental Association (ADA), the topical application of fluoride should take caries risk status into consideration. The caries risk criteria are as follows:

Patients should be evaluated using caries risk criteria such as those below.
Low caries risk
All age groups
No incipient or cavitated primary or secondary carious lesions during the last 3 years and no factors that may increase caries risk*
Moderate caries risk
Younger than 6 years
No incipient or cavitated primary or secondary carious lesions during the last 3 years but presence of at least one factor that may increase caries risk*
Older than 6 years (any of the following)
One or two incipient or cavitated primary or secondary carious lesions in the last 3 years.
No incipient or cavitated primary or secondary carious lesions in the last 3 years but presence of at least one factor that may increase caries risk*
High caries risk
Younger than 6 years (any of the following)
Any incipient or cavitated primary or secondary carious lesion during the last 3 years
Presence of multiple factors that may increase caries risk*
Low socioeconomic status†
Suboptimal fluoride exposure
Xerostomia‡
Older than 6 years (any of the following)
Three or more incipient or cavitated primary or secondary carious lesions in the last 3 years
Presence of multiple factors that may increase caries risk*
Suboptimal fluoride exposure
Xerostomia‡

**Factors increasing risk of developing caries also may include, but are not limited to, high titers of cariogenic bacteria, poor oral hygiene, prolonged nursing (bottle or breast), poor family dental health, developmental or acquired enamel defects, genetic abnormality of teeth, many multisurface restorations, chemotherapy or radiation therapy, eating disorders, drug or alcohol abuse, irregular dental care, cariogenic diet, active orthodontic treatment, presence of exposed root surfaces, restoration overhangs and open margins, and physical or mental disability with inability or unavailability of performing proper oral health care.*
†On the basis of findings from population studies, groups with low socioeconomic status have been found to have an increased risk of developing caries. In children too young for their risk to be based on caries history, low socioeconomic status should be considered as a caries risk factor.
‡Medication-, radiation-, or disease-induced xerostomia.

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