# Topical Effects of Fluoride in the Reversal and Prevention of Dental Decay

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**Abstract**

*This paper briefly reviews the clinical evidence for, and the science behind, the topical effects of fluoride in the inhibition and reversal of dental caries. Fluoride from topical sources such as drinking water, mouthrinses, dentifrice, and office-applied gels and foams inhibits demineralization and enhances remineralization. Inhibition of demineralization occurs when fluoride diffuses into the tooth and adsorbs to the crystal surfaces, protecting them from further acid attack. During times when the plaque pH is raised by salivary buffering, remineralization takes place through calcium and phosphate diffusing to the crystal surfaces in the subsurface lesion and building a new veneer on the remaining crystal remnants in the lesion. Fluoride speeds up this process, is incorporated together with calcium and phosphate, and leaves the crystal much more acid resistant. Remineralization is the body's natural caries repair process.*

## H. S. Horowitz

It is an honor for me to present this review of the topical effects of fluoride as part of the symposium honoring Hersh Horowitz. I first knew Hersh through his published literature when I embarked on dental research in the early 1970s. He published numerous studies relating to the topical effects of fluoride by way of clinical studies that demonstrated the efficacy of several modes of delivery. I met Dr. Horowitz in the late 1970s and often attended the same scientific meetings that he did, always respecting his direction, which was to provide the best means of delivering fluoride for the benefit of individuals and populations.

## Clinical Proof of Topical Fluoride Effects

There is abundant clinical proof of the posteruptive (topical) effects of fluoride in reducing or inhibiting dental decay. Only a few are reviewed here. There are numerous clinical trials that have shown approximately 30% reduction in caries with the use of fluoride dentifrice with concentration generally in the range of 1,000 to 2,800 ppm F (1-4). Lower and higher concentrations have been studied and also been shown effective (5,6). One recent paper of particular note is by Curnow et al. (7), who reported 32–56 percent reduction in dental caries with daily supervised brushing with a fluoride-containing dentifrice compared to a matched group of schoolchildren who supposedly utilized fluoride dentifrice at home. This illustrates the efficacy of daily fluoride use in maintaining a level of fluoride that enhances the posteruptive fluoride effect.

Over-the-counter fluoride rinses (0.05% sodium fluoride) have also been shown to be very effective in high-caries-risk patients when used once or twice daily for one minute in conjunction with a fluoride-containing dentifrice. One such study was by O'Reilley and Featherstone, who showed complete inhibition of caries progression around orthodontic brackets in teenagers when the two fluoride sources were utilized in comparison to measurable decay when only the fluoride dentifrice was used (8).

Root caries can also be inhibited by the use of fluoride dentifrice as first shown by Jensen and Kohout (4). A recent study by Baysan et al. showed that a 5,000 ppm fluoride dentifrice was more effective than a 1,100 ppm fluoride dentifrice for the control of root caries (5). This further demonstrates that in the case of high-risk individuals higher concentrations of fluoride are necessary.

Fluoride products applied in the dental office have been shown by several studies to be effective even when only utilized, for example, at six-month intervals. These products include 5,000 ppm F gel or foam and most recently fluoride varnish applications (9). These high concentration office topicals overcome the compliance problems and provide an effect for several weeks most likely due to the precipitation of calcium fluoride at the time of application, which slowly dissolves to provide free fluoride to inhibit demineralization or enhance remineralization.

Fluoride in drinking water at 1 ppm is also effective posteruptively in children and adults as illustrated by several studies. For example, Hardwick et al. showed a caries reduction of approximately 27 percent over 4 years in 12-year-olds who had grown up in a nonfluoridated drinking water area and who were 12 years old at the time their drinking water was fluoridated (10). Stamm et al. reported a reduction in root caries in older adults living in a fluoridated drinking water area (11). These and other studies indicate that even 1 ppm fluoride in the drinking water is sufficient to provide a topical effect as shown by clinical studies.

The conclusion we must draw from the clinical studies and epidemiologic studies is that various topical sources of fluoride are effective posteruptively in children and adults. This means when we consider caries preventive and interventive modalities, topical fluoride daily or in the dental office should be used for all ages. So the question arises: what are the mechanisms involved? Many laboratory and intraoral investigations have elucidated the mechanism and the three modes of action of fluoride applied posteruptively are described below.

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## Dental Mineral

The mineral in our teeth and bones is a highly substituted carbonated hydroxyapatite (12,13). This is a calcium phosphate in which the calcium is substituted by numerous trace elements including sodium, phosphate is highly substituted by carbonate, and some of the hydroxyl ions are replaced by fluoride ions. Pure hydroxyapatite, which does not exist as such, and the mineral of our teeth is orders of magnitude less soluble than the biological carbonated apatite (14-16). Fluorapatite, in which all of the hydroxyl groups are replaced by fluoride, is orders of magnitude less soluble again. During remineralization (described below) a mineral somewhere between hydroxyapatite and fluorapatite is formed on the surface of the partially dissolved enamel or dentin crystals (17).

## Demineralization

Dental caries is simply described as demineralization, or loss of mineral from the tooth. The acid soluble dental mineral is dissolved by organic acids produced by the bacteria when they ferment dietary carbohydrates (17). This produces soluble calcium and phosphate which diffuse out of the tooth, eventually leading to cavitation if the process is not stopped or reversed. Fluoride in solution among the crystals of enamel or dentin is adsorbed onto the surface of the crystal and inhibits mineral loss (17,18). Fluoride from topical applications of, for example, dentifrice supplies sufficient fluoride to markedly inhibit the acid dissolution of the crystals. Early studies by Featherstone and co-workers showed that the calcium-deficient/carbonate-rich areas of the crystals of dental enamel preferentially dissolved by acid (19,20). When fluoride is adsorbed onto these surfaces, this dissolution of the weak areas in the crystal is greatly inhibited. This is being shown experimentally in several reports; for example, Featherstone et al. (21) used a carbonated apatite in an acid dissolution apparatus in which fluoride was added to the acid buffer at concentrations ranging from 1–50 ppm. The reduction in dissolution rate was logarithmic with the fluoride concentration. This gave proof of the mechanism of fluoride inhibition of demineralization due to adsorption of the fluoride ion. Other studies utilizing extracted teeth have shown major inhibition of demineralization by the presence of a few parts per million fluoride in the acid buffer, and this is comparable to the levels present in the plaque fluid in the mouth (18,22).

In summary, the first topical mechanism of action of fluoride is that fluoride inhibits demineralization by adsorbing from solution onto tooth mineral crystal surfaces inside the tooth.

## Fluoride Inhibition of Bacteria

Several reports have led to the conclusion that fluoride cannot enter bacteria in the ionic form. However, when combined with the hydrogen ion, HF is formed, which readily diffuses into the cells (23). When the HF is inside the bacterial cell, this dissociates again into free fluoride and hydrogen ion, interfering with several enzyme actions within the cell (23). The bottom-line conclusion is that as the cariogenic bacteria produce acid, the hydrogen ions liberated can combine with free fluoride in the plaque fluid, diffuse back into the cell as HF, and interfere with the enzyme actions in the cell, either slowing down the cells or killing them. The second mechanism of topical action of fluoride, therefore, is the inhibition of cariogenic bacteria.

## Remineralization

Remineralization is the putting back of mineral into a carious lesion (17,18,24). Remineralization is the natural repair process for carious lesions. Ideally, during remineralization, new mineral is formed that excludes most of the substitutions originally there in the mineral, making a much less soluble mineral. The demineralized crystals in a carious lesion either in the enamel or in dentin exist as crystal remnants. During the acid attack and demineralization, mineral is partially removed from the surfaces of the crystals and, if acid attack continues, these crystals can dissolve completely. However, if the demineralization is interrupted by buffering by saliva and/or the carbohydrate source is removed from the bacteria, the pH rises and remineralization occurs. The fluoride present in the plaque fluid or in the saliva travels into the carious lesion, together with the calcium and phosphate. The fluoride is attracted to the calcium ions within the crystal remnants, thereby attracting further calcium ions to the fluoride, and the calcium attracts more phosphate and more fluoride, and so on, until a new crystal surface is formed. This is described in more detail in other publications together with diagrammatic representation of the process (17,18). The bottom line is that fluoride speeds up remineralization and produces a much less soluble fluorapatite-like veneer on the crystals. The next wave of acid attack is unable to dissolve this mineral and must go deeper into the tooth (17,18,25). In summary, fluoride enhances remineralization and makes the remineralized crystals more resistant to subsequent acid attack.

## Clinical Relevance of Remineralization

As stated above, remineralization is the natural repair mechanism for dental caries. Fluoride from various topical sources is effective posteruptively in adults as well as children to repair and reverse early carious lesions. We know the mechanisms involved, we know that several fluoride sources—including fluoride in the drinking water—can enhance remineralization, but we must give remineralization a chance in cases where the acid challenge is high. Fluoride is effective only up to a point and high bacterial challenge overcomes the effects. Thus, in high-risk individuals with markedly elevated cariogenic bacterial levels, the bacterial levels must be reduced for remineralization to be truly effective (26-28). How then can we use this information in the future for better caries prevention and reversal at all ages?

I recently proposed a caries balance in which pathological factors including acid producing bacteria, subnormal saliva function, and frequent eating of fermentable carbohydrates is balanced by protective factors, which include saliva flow and components, fluoride/remineralization, and antibacterial action (26-28). In recent publications, this principle has been described as to how it can be used for the caries risk assessment and caries management (26-28). Essentially the guiding principle is to bring the environment of the teeth into balance and maintain it there, so that caries does not progress, or may indeed be reversed. This requires not only fluoride therapy, but antibacterial therapy, behavioral modification, saliva enhancement, and preventive or restorative treatments that enhance the preven-

tive side of the caries balance.

## Conclusions

In summary, fluoride has been shown by numerous clinical studies to have a major posteruptive effect in children and adults. As a result of many laboratory and in situ experiments, we have a very good understanding of how fluoride works and we can use this knowledge to provide more effective caries-preventive measures. Fluoride inhibits demineralization, inhibits cariogenic bacteria, and enhances remineralization. Remineralization is the natural repair process for carious lesions. In the case of high-caries individuals with high numbers of cariogenic bacteria, antibacterial therapy must be used to allow the remineralization and repair to be effective.

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