Rational use of fluorides in caries prevention

A concept based on possible cariostatic mechanisms

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The aim of this review has been to suggest that future fluoride preventive programs should be based on what is at present known about the possible cariostatic mechanisms of fluoride. The relative role of enamel fluoride in caries prevention has become increasingly questioned during the last two decades. No significant relationship has been demonstrated between caries experience of the individual and fluoride content of the enamel. Furthermore, the fluoride content in surface enamel between teeth developed in low and «optimal» fluoride areas is too small to explain any significant effect on dissolution rate of the enamel. As the major explanation for the cariostatic effect of fluoride must therefore be sought in its local effect on the oral environment, the possible effects on plaque colonization, composition and metabolic activities are discussed. The effect of even low concentrations of fluoride in the liquid phase on enamel dissolution is described, and it is concluded that the major cariostatic effect of water fluoridation, fluoride tooth paste and mouth rinses can probably be ascribed to regular increases in fluoride ion activity in the oral fluids. The effect of high concentrations of topical fluoride solutions is thought to be a result of a slow dissolution of calcium fluoride deposited in initial caries lesions, whereby an increased fluoride ion concentration is maintained locally for longer periods of time. Finally, the clinical consequences of these considerations are described.

Key-words: Clinical assessments; fluoride content of enamel

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Despite the effort of half a century to elucidate how fluoride works in caries prevention, it is striking that no definite answer has yet been given (for review see 7). Thus, the questions raised by Dean (14) in his excellent report on endemic fluorosis and its relation to dental caries still remain unanswered. This may not be so surprising, however, if it is acknowledged that the basic pathogenic mechanisms behind both dental and skeletal fluorosis are obscure as well (13, 22).

The observation that ingested fluoride interfere with the mineralization pattern in both enamel and dentine in a very similar way (23) indicate that the understanding of the cariostatic potential of fluoride may be closely associated with current attempts to disclose

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the basic principles in biological mineralization.

Because of this uncertainty about the cariostatic mechanisms of fluoride considerable effort has been spent on clinical trials in which the effects of a variety of fluoride regimes have been tested (5, 18, 19, 20, 47). It is generally accepted that topical fluoride programs exhibit a somewhat lower caries percentage reduction than does water fluoridation, but obviously little concern has been given to the fact that the effect of different rinsing solutions appear similar irrespective of great variations in fluoride concentration, fluoride ion activity, pH etc. of the solution (37). Rather than testing the effect of variations in these parameters on caries increments in costly clinical trials, it seems benificial to reconsider what is at present known about possible mechanisms.

THE MOST POPULAR CONCEPT

Until recently most caries preventive programs using fluoride have aimed at incorporating fluoride into the dental enamel. The relative rôle of enamel fluoride in caries prevention is now being increasingly questioned, and based on rat experiments (41) and reevaluation of human clinical data (44), it appears to be of minor importance. Therefore it is generally accepted that more than one mode of action may be involved (4, 45). As mentioned above, the most common belief is that fluoride should be incorporated into the enamel in order to reduce caries by forming hydroxyfluorapatite, which is more resistant to acid dissolution (28).

This concept is based on the findings that teeth formed in communities with 1.0–1.5 ppm fluoride in the water supplies have about 50 % less caries than expected (2, 3, 15). Such teeth have an increased fluoride content in the surface enamel (9, 29). It was natural, therefore, to consider this as a cause- and effect-relationship (10), as it was further shown that apatite crystals in bone formed under the influence of fluoride appeared more perfect (64), and clinically the enamel was considered better or «optimally» mineralized (48).

FLUORIDE IN ENAMEL

The fluoride concentration in the bulk of enamel is relatively low and reflects fluoride incorporated during enamel formation. The concentration depends on the amount of fluoride ingested from various sources such as water, food or fluoride supplements (11). The much higher concentrations in the outer 30–50 μm enamel surface is acquired mainly during the postsecretory phase of enamel formation prior to tooth eruption (60).

The concentration in surface enamel varies depending on depth of sampling, sampling technique, age of the tooth, and may vary from area to area over the surface of the tooth (11, 12, 20, 28, 30, 45, 51, 61, 62, 65, 66, 68). It is a general trend, however, that the length of the preeruptive maturation phase influences the amount of fluoride acquired. Thus, deciduous teeth from a fluoride area contain much less fluoride in the surface enamel than the permanent teeth from the same area, and even less than permanent teeth developed in a low fluoride area (45). Consequently it is important to consider that the effect of systemic fluoride on caries prevalence in the primary dentition is of similar magnitude as that of the permanent dentition, irrespective of amount of incorporated fluoride during tooth formation (57).

RELATIONSHIP BETWEEN ENAMEL FLUORIDE AND CARIES

It is an interesting fact that the difference found in fluoride concentration of surface enamel between permanent teeth from low and optimally fluoridated areas is so limited (9, 29, 30, 39, 45); it is extremely difficult in this way to explain the 50 % reduction of caries observed in communities with about 1 ppm F^- in their water supplies. Much emphasis has during the years been put on the acid resistance of hydroxyfluorapatite, but it is noteworthy that complete substitution of hydroxyl ions in human enamel corresponds to a fluoride content of 3.7 %. However, even in severely fluorosed human enamel such a complete substitution is never achieved as less than ¼ of the hydroxyl ions in the outer enamel have been replaced by fluoride (50). In human enamel formed in areas with 1–1.5 ppm F^- in the water we are operating with much smaller concentrations as the substitution amounts to only 10 % corresponding to about 3,000 ppm of fluoride in the outer enamel.

The insignificant role played by such small amounts of incorporated fluoride in the tissue is illustrated by observations *in vitro* when teeth formed in «low» and «optimal» fluoride areas developed exactly similar lesions after continuous exposure to an acidified gel. Interestingly enough this finding was reproduced following removal of the outer fluoride rich surface enamel in both groups of teeth (30). With this in mind it is not surprising that it has hitherto been difficult to demonstrate any clear-cut inverse relationship between fluoride content of surface enamel and dental caries (16, 49, 51, 53, 56).

These considerations thus raise doubt as to the validity of the concept of caries prevention being a simple function of enamel fluoride concentration. Finally, it should be emphasized that Brudevold, McCann & Grön (10) and Brown, Gregory & Chow (6) have concluded that the rate of acid solubility is of little importance in protecting the tooth against caries.

STUDIES SHOWING A PREDOMINANTLY TOPICAL EFFECT OF FLUORIDE

All these observations combined explain why the cariostatic effect of topical fluoride regimes are found without any concommitant increase of fluoride concentration in sound enamel (8). Thus, frequent fluoride mouthwashes (67) or chewing of fluoride tablets (54) gave rise to a distinct caries reduction without significant increase in fluoride concentration in sound buccal enamel. In addition DePaola et al. (17) found an almost similar caries reduction after daily use of ammonium or sodium fluoride rinses containing 1,000 ppm F^-, despite the fact that NH_4F deposited considerable amounts of fluoride in the enamel during the experimental period opposite to NaF.

It is thus obvious that the cariostatic effect of any sort of fluoride treatment should be sought in its effect on the local environment surrounding the tooth surface.

This concept is not in contradiction with clinical data from fluoridated areas as these collectively indicate that waterborn fluoride is particularly effective during the periods in life were caries develop (47). It is a general impression that certain surfaces receive selective protection from water fluoridation (3). Unfortunately this statement has to some extent overshadowed the observation that the distribution pattern of caries within the mouth in areas with different concentrations of fluoride in the drinking water is in principal maintained (47, 48). This maintenance of the basic decay attack pattern within the mouth in optimally fluoridated areas thus suggests that fluoride predominantly exerts its effect through its capacity to interfere with the post-eruptive environment rather than through an inherent fluoride factor of the enamel.

Finally, the importance of fluoride being present in the oral fluid during caries active periods can be seen from the results obtained when water fluoridation or topical fluoride treatment is discontinued (26, 27, 42). If an individual is still in a caries active phase an increased number of lesions will appear.

THE EFFECT OF FLUORIDE ON DENTAL PLAQUE

When considering the topical effect of fluoride in caries prevention, it is natural to look at how it affects dental plaque. In principle, fluoride may interfere with plaque colonisation, plaque composition and/or metabolic activities within the microbial deposits.

Based on clinical data it has been claimed that children from fluoride areas accumulate less plaque than do children from low fluoride areas. Laboratory tests have indicated that fluoride incorporated into the apatitic lattice changes the adsorption selectivity of enamel for specific aminoacids and salivary macromolecules (46). Furthermore, it has been suggested that fluoride present in the liquid phase might desorp protein and bacteria from hydroxyapatite (52). However, controlled studies in humans have shown that high concentrations of fluoride, whether present in enamel or in oral fluids, do not change rate and/or composition of early plaque formation (32, 59).

Very little is known about possible effects of fluoride on microbial composition of plaque, but a comprehensive microbiological study of predominant plaque flora of children exposed to high and low water fluoride concentrations was unable to detect any significant difference (33).

There is no doubt, however, that fluoride may interfere with bacterial metabolism (24, 31). That this may be of clinical significance has been convincingly shown by Shields & Mühlemann (55). A slight increase in fluoride ion concentration (0.10–1,9 ppm) was sufficient to almost prevent a simultaneous saccharose-induced pH drop in 4–6 day old plaque. Furthermore, it may be of importance that plaque microorganisms are able to accumulate fluoride intracellularly at low pH (63). The significanse of these findings are not yet fully understood, but it is tempting to believe that the effect on plaque metabolism may contribute to the cariostatic effect of fluoride.

A POSSIBLE EXPLANATION OF THE PREDOMINANT CARIOSTATIC EFFECT OF FLUORIDE

In order to understand how fluoride may exert its effect on dental caries, it is necessary to have in mind that the clinically detectable caries lesion is a result of innumerable pH drops in the dental plaque covering the enamel.

The enamel surface is not chemically inactive or inert, but is constantly subjected to exchange reactions with the oral fluid. At caries susceptible sites the marked fluctuations in pH will bring about frequent dissolution and reprecipitation of minerals. The authors of the present paper suggest that the major reason for the cariostatic effect of fluoride can be ascribed to its ability to influence these processes even at very low (0.2–1 ppm) concentrations by facilitating calcium phosphate precipitation.

This is in accordance with Brudevold, McCann & Grön (10) who came to the conclusion that the role of fluoride in caries prevention can be ascribed to its unique ability to induce apatite formation from solutions of calcium and phosphate. Saliva in itself is an excellent solution for remineralization (1, 24, 34), but fluoride treatment significantly increases the rate of remineralization as shown by von der Fehr, Löe & Theilade (21).

It is remarkable that only traces of fluoride (0.2 ppm) are required in a solution with calcium present at pH 4.2 to reduce markedly the rate of dissolution of enamel (43). Furthermore, Joost Larsen, von der Fehr & Birkeland (38) showed that addition of low concentrations of fluoride (0.1–1.0 ppm) into a liquid at pH 5.0, which is saturated with respect to hydroxyapatite and in contact with this solid, gives rise to a rapid formation of fluorapatite. A low fluoride ion activity in the liquid was thus able to reduce the amount of calcium and phosphate dissolved. The authors concluded that the theory of the solubility reducing effect of fluoride and the theory of remineralization can to some extent be considered to be two aspects of the same process.

What appears to be important in reducing the solubility of the enamel is the fluoride ion activity in the oral fluid rather than a high content of fluoride in enamel. These results, based on simple chemical experiments, explain why fluoride accumulates in cervical enamel below dental plaque with age (51, 62). Consequently, surface enamel fluoride at caries susceptible sites may simply be an indicator of the environmental conditions at the plaque-enamel interface lifelong.

In consequence the cariostatic effect of water fluoridation, salt fluoridation, fluoride toothpaste and mouth-rinses can be ascribed to the regular (daily or weekly) increase in fluoride ion activity in oral fluid.

Topical application of high concentrations of fluoride (2 % NaF, 8 % SnF_2, APF, etc.) gives rise to formation of calcium fluoride on normal enamel. As this salt is soluble in saliva, it gradually dissolves, and thereby an increased fluoride activity is observed in oral fluid up to 24 hours after treatment. It has recently been shown that the fluoride concentration in saliva 2 and 4 hours after treatment is sufficient to increase remineralization of dental enamel significantly; more than does normal saliva (36). In areas where carious lesions are at different stages of development, calcium fluoride may accumulate deep in the porous enamel (40) whereby a prolonged effect in the micro-environment of the lesions may persist for days, weeks or even months.

Recently, Koulourides et al. (35) have shown that enamel which had been made porous for 8 days prior to fluoride treatment exhibited higher resistance to an intraoral cariogenecity test for 4 weeks than did fluoride treated normal enamel. Whether this should be considered as an indication of increased resistance of the early enamel lesion as suggested by these authors, or rather as an excellent example of a prolonged effect of fluoride release from a calcium fluoride reservoir in the porous enamel, should be further investigated.

CONCLUSIONS

Based on these considerations it is obvious that fluorides used in caries prevention may in reality be considered as an outstanding method for caries treatment at subclinical and clinical levels. As a direct consequence any method which places particular emphasis on incorporation of bound fluoride into dental enamel during formation may be of limited value. Therefore, there is limited scientific data to support the assertion that systemic fluoride treatment should be initiated from shortly after birth. During the first years of infancy mothers are overwhelmed by several other health preventive measures. Concommitant with the eruption of primary molars instruction in oral hygiene and reasonable dietary habits with limited intake of fermentable carbohydrates should be initiated together with various types of fluoride treatment.

The choice of fluoride program(s) will then depend on the dental health system (numbers and categories of health personnel), attitudes to water fluoridation in the community and solid data on caries prevalence and incidence in the population.

That topical fluoride programs together with daily use of fluoride toothpaste is not to be considered as a second class type of caries treatment as compared to water fluoridation is clearly demonstrated by the results obtained in the Danish Child Dental Health Program (58). In Fig. 1A & B the development in DMF-S between 1973 and 1980 is seen in a water fluoride area (1.5 parts/10^6F^-) and in two low fluoride areas (<0.4 parts/10^6F^-) among 1st and 9th grade children. Child dental health service has been operating in all three areas for more than 20 years.

Based on our present knowledge obtained from epidemiological studies, clinical trials, microbiologic and clinical studies, laboratory experiments and theoretical physico-chemical considerations, considerable evidence is available to substantiate the assertion that fluoride, even in low concentrations, is necessary in the oral fluids to obtain maximum caries inhibition. The relative significance of fluoride bound in the enamel remains uncertain. Therefore continuous or frequent supplementation to oral fluids is mandatory, particularly in cases of increased cariogenic challenge at any age.

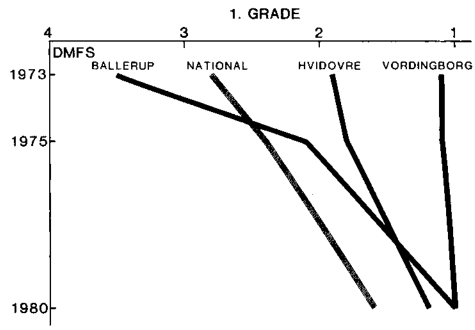

Fig. 1 A

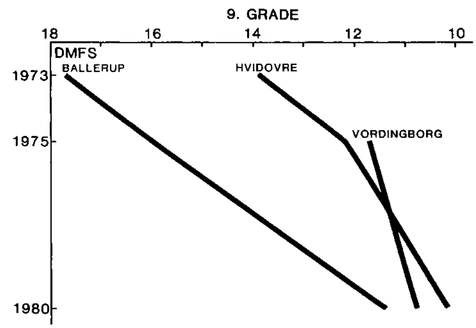

Fig. 1 B

Fig. 1 A and B. Development in DMF-S 1973–1980 in a F-area (Vordingborg, 1.5 parts/10^6F^-) and in two low F areas (Ballerup and Hvidovre, ≤ 0.4 parts/10^6F^-) among 1st grade children (A) and 9th grade children (B). The number of children examined each year is approximately 380 (Vordingborg), 960 (Ballerup) and 700 (Hvidovre). In addition Fig. 1 A indicates mean number of DMF-S for the entire nation. Data originate from the Danish Child Dental Health recording system (58).

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