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Enamel fluoride uptake from a new APF foam

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Abstract

There is concern that the ingestion of fluoride (F) from topical application of 1.23% APF gel may cause gastric irritation and other side effects. In this in vitro study, a newly developed APF-based foam was tested. Sound human enamel was treated for 4 min with APF foam or a conventional APF gel (Nupro®), both containing 1.23% F. Enamel biopsies were obtained using the acid-etch technique. There was a significant increase ($P < 0.001$) in F uptake from the two F agents compared with their untreated controls. The uptake of F from the new foam and Nupro gel in the outer 15 μm enamel were 1736 and 2596 ppm, respectively. The difference in F uptake from the foam and gel preparations at 5 μm depth was not statistically significant ($P = 0.074$). Clinically, the amount of foam needed for full-mouth treatment is less than 1 g, whereas for APF gel it is nearly 4 g.

The topical application of acidulated phosphate fluoride (APF) gels has been demonstrated by clinical studies to reduce dental caries to an average of 25% (Clarkson and Wei 1982; Mellberg and Ripa 1983). The Accepted Dental Therapeutics (1984) listed 22 APF gels accepted by the American Dental Association (ADA). Most of these gels contain 1.23% F (as NaF and HF), 1% phosphoric acid and carboxymethyl cellulose as the gelling base. The pH is usually between 3.0 and 4.5 and the viscosity of 7000 to 20,000 centipoises. Fluoride gels have the advantage of being used in trays, enabling the entire mouth to be treated in a single application. Because the F gels are viscous, the use of a well-fitting tray is essential to facilitate the flow of the gel into the interproximal surfaces of teeth.

Concern has been expressed recently about the potential risk of excessive F ingestion following application of 1.23% APF gels. Ekstrand et al. (1981) reported that an average of 78% (31.2 mg F) of topically applied 1.23% APF gels was ingested when vacuum-molded trays were used on children 5-16 years of age. LeCompte and Whitford (1981) reported that the average amount of F retained by children approached 14 mg or 54% of the applied dose using the cotton-roll isolation technique. However, the amount of F ingested was greatly reduced when suction was applied and when better fitting trays were used (LeCompte and Doyle 1985). The ingested F from APF gels may cause side-effects such as nausea, vomiting, and gastrointestinal pain.

Recently, in vitro evidence indicated that there is no direct relationship between the F content of APF gels and their ability to reduce enamel solubility, (Shannon and Edmonds 1978; Hattab 1984), increase enamel F uptake, (Dijkman et al. 1982; Naleway 1985), and decrease the carious lesion depth (Sluiter and Purdell-Lewis 1984). Based on these findings and the concern for the potential risk of overdosage, suggestions have been made to lower the F concentration in gels and/or to use a well controlled application technique. In an attempt to minimize the risk of F overdosage and to maintain the efficacy of topical F treatment, a new foam-based APF agent has been developed.

The aim of the present study was to determine whether a foam-based APF agent is effective in producing enamel F uptake to concentrations attained by conventional APF gels. Because the foam is considerably lighter than gels, it will fill a topical application tray with a much smaller weight of the agent and hence the total amount of F ingested could potentially be less. This will be the subject of a subsequent study.

Materials and Methods

A total of 40 premolars, extracted for orthodontic reasons, free of defects and showing no signs of caries or hypoplastic lesions on the buccal aspects, were utilized in this study. The teeth were cleaned with an aqueous slurry of pumice and washed with water. Two round adhesive disks 4mm in diameter were placed on the mesial and distal aspects of the buccal surface. The disks were burnished onto the enamel surface to assure a good peripheral seal and all tooth surfaces were covered with acid-resistant nail varnish. The mesial and distal enamel circles covered with the disks were chosen at random to serve as test (F-treated) or control (F-untreated) surfaces. In this way each tooth served as its own control.

Treatment Procedure and Enamel Biopsy

The disk covering the control area was removed leaving behind a varnish-free enamel surface window of 12.6 mm^2. Acid-etch biopsies were carried out using F-free cotton pellets. The pellet was saturated with 0.1 ml of 0.5 M $HClO_4$ and held with forceps against the window for 15, 30, and 30 sec consecutively. Immediately after each etching, the etchant was buffered by directly pipetting onto the enamel 0.4 ml of 0.5 M citrate buffer followed by 0.5 ml of deionized water. The residual solution left on the tooth surface was aspirated with a microsampling pipette and small pieces of F-free filter paper and transferred to the original sample solution. The biopsied control window was covered with nail varnish and the disk of the test area then was removed. The test windows were treated with one of the following: APF foam[a] containing 1.23% F, sucrose esters, and nonionic surfactant (pH 3.5); or Nupro® gel[b], an APF gel containing 1.23% F from sodium fluoride and hydrogen fluoride (batch 5M5823). The windows were exposed for 4 min to the F agents at room temperature in a relative humidity of 100%. Immediately after F treatment, the enamel surfaces were washed for 30 sec under running tap water and for 1 min under running deionized water.

Chemical Analysis and Data Evaluation

The F concentrations in the solutions containing the biopsied enamel were determined using combination F-ion electrodes[c] coupled to a digital ionalyzer.[d] The phosphate concentrations in the samples were determined by a double-beam spectrophotometer[e] using the malachite green method (Hattab and Linden 1984).

The mass of enamel in each sample was calculated by assuming that enamel contains 17.5% phosphorus. The thickness of the biopsied enamel layers was estimated from the following formula:

$$\text{Layer Thickness } (\mu m) = \frac{\text{Mass of enamel } (\mu g)}{\text{Biopsy area } (mm^2) \times \text{Density of enamel}}$$

Because the thicknesses of the biopsied layers are not totally controllable and because of the very steep F gradient in the outer enamel, the mean F concentrations were adjusted to standardized depths of 5, 10, and 15 µm from enamel F profile (Hattab 1987).

The paired *t*-test was used to evaluate the differences in enamel F concentrations between the test and control windows of each F treatment and between the two treatments (APF gel and APF foam).

[a] Block Drug Co Inc; Jersey City, NJ.
[b] Johnson & Johnson Dental Products Co; East Windsor, NJ.
[c] Orion model 960900 — Orion Research Inc; Cambridge, MA.
[d] Orion model 901 — Orion Research Inc; Cambridge, MA.
[e] Shimadzu model UV-150-02 — Shimadzu; Tokyo, Japan.

Results

Measurements of phosphate allowed the determination of the relationship between etch depth and F concentration.

The mean (±SD) thickness of enamel layers removed after 15, 30, and 30-sec etching were 3.16 ± 0.40, 5.30 ± 0.44, and 5.76 ± 0.64 µm, respectively. There were no significant differences in the thickness of enamel layers removed from the control and F-treated groups. The total thickness of the three layers was 14.22 µm. The precision of the enamel biopsy was 11.7% (N = 240).

The mean concentration of F found at standardized depth of the control and test (F-treated) groups are shown in the Table. The data are graphically presented in the Figure. With the control group, the F concentra-

TABLE. Mean Fluoride Concentrations at Standard Enamel Depths Before (Control) and After 4-min Treatment With 1.23% APF Foam or Conventional Nupro® Gel.

Topical Agent	*F Concentration (ppm) at Standardized Depths (mean ± SD)*		
	5 µm	*10 µm*	*15 µm*
Foam			
Control	2133 ± 628	1683 ± 369	1392 ± 302
Treated	5579 1994	2879 834	1957 635
Net F acquired	3446 2125	1196 836	565 591
Gel			
Control	1952 619	1387 355	1133 273
Treated	6517 2542	3369 1330	2373 1023
Net F acquired	4565 ± 2388	1982 ± 1268	1240 ± 960

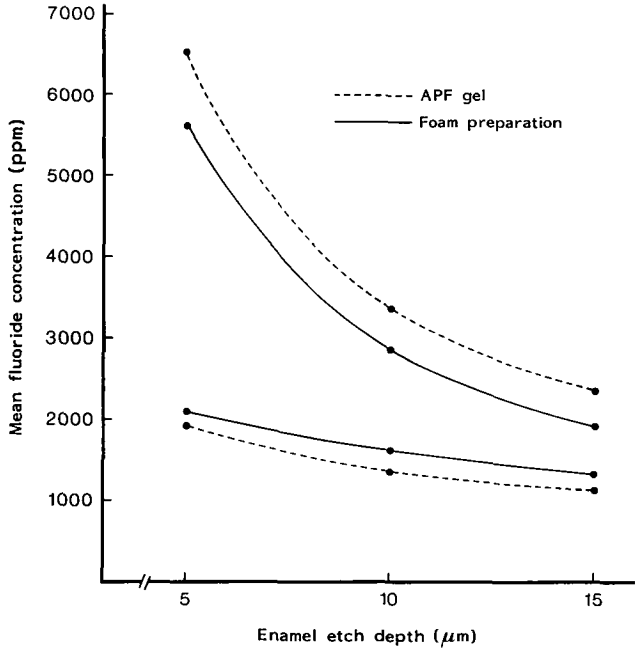

FIGURE. Mean fluoride concentrations at standardized depths of enamel treated for 4 min with 1.23% APF foam or 1.23% (Nupro®) gel. The lower curves represent the controls (F-untreated).

tion in the first 5-μm depth was 1.33 times more than the second depth (10 μm) and 1.62 times more than the third depth (15 μm). Both F treatments resulted in significant F uptake at all enamel depths ($P < 0.001$, t values ranged between 4.27 and 8.55). The net F acquired, i.e., treatment minus the control, at the outer 15-μm thick enamel was 1736 ppm for the APF foam treatment and 2596 ppm for APF gel. The paired t-test showed no significant difference in the amount of acquired F from both F treatments at 5-μm depth ($P = 0.074$, t value = 1.89). At depths 10 and 15 μm, APF gel resulted in F uptake significantly higher than for the APF foam ($P < 0.025$, t values = 2.64 and 2.67). There was a linear/logarithmic relationship between the depth and acquired F for both treatments. The slope of the generated regression line for foam and APF gel were -1.30 and -1.19, respectively. The correlation coefficient was 0.99.

Discussion

The uptake of F from APF involved two separate reaction processes. An initial and almost instantaneous surface adsorption process was noted whereby dissolution of enamel mineral and reprecipitation of F-rich reaction products onto enamel surface occurs. This uptake is followed by a diffusion-controlled process of F penetration into interprismatic areas and its interaction with enamel crystallites (Brudevold et al. 1963; Joyston-Bechal et al. 1973). The principal chemical product of the surface adsorption reactions is calcium fluoride (CaF_2). Earlier experimental findings showed that CaF_2 deposit can be washed away with water in about 24 hr or slightly longer (Mellberg et al. 1966; Richardson 1967) or it can be totally extracted in 1 M potassium hydroxide after 24 hr (Caslavska et al. 1975). This finding has led some workers to question the beneficial effects of the reaction product, CaF_2. Ample current evidence showed that the dissolution of CaF_2 in human saliva, both in vitro and in vivo, is a rather slow process and may continue for several weeks.[1] Significant remineralization and caries reduction have been reported in F treatments where the main reaction product is CaF_2.[2]

The brief washing step following F treatment used in the present study was intended not to interfere or mask the effects of the tested F agents on F uptake by enamel. It may be argued that the primary action of F is at the sites of carious lesions rather than on sound enamel. However, in an apparently sound enamel the white spot lesion is not easily detectable either clinically or radiographically until involvement of the dentin has occurred (Silverstone, 1985). Accordingly, increasing the F concentration in sound enamel may protect it from demineralization during cariogenic challenges. In a recent study on F uptake in sound enamel and caries-like lesions from F solutions, a strong correlation (r = 0.99) in F uptake between the two types of enamel surfaces has been found (Hicks et al. 1986). The caries-like lesions acquired about 1.2-fold more F than sound enamel.

Following F treatment, a variable amount of F is ingested, depending on the product's F concentration, its physical property, subject age, and the application technique. Another variable that would affect the amount of F ingested is the amount (or volume) originally introduced in the mouth. With the exception of F gels, the amount of F retained from topical treatments, almost all of which is ingested, rarely exceeds 1 mg (Wei and Hattab [in press]). Applications of a 1.23% F gel with different trays and techniques have resulted in amounts of F ingested ranging between 14 and 31.2 mg (Ekstrand et al. 1981; LeCompte and Whitford 1981). In order to reduce the potential over-dosage from 1.23% APF gels, suggestions have been made to: (1) lower the F concentration in the agent; (2) construct individual trays with a suction device; (3) rinse following gel application; and (4) shorten the application time. While the use of individual trays makes the treatment more costly, rinsing following application may significantly reduce the efficacy of treatment (Stookey et al. 1986). On the other hand, shortening the application time to 1 min, as suggested by the manufacturer of Minute-Gel™ [f] has resulted in a significant decrease (2.5-fold) in the uptake of F compared to 4-min treatment (Wei and Hattab 1987; Wei and Hattab [submitted for publication]). These studies and others (Joyston-Bechal et al. 1973) clearly demonstrate that the uptake of F in enamel is time dependent.

A foam-based APF agent has two advantages: (1) it is much lighter than a conventional gel and therefore only a small amount of the agent is needed for topical application (e.g., the amount of conventional gel needed to treat the mouth is about 4 g while less than 1 g of foam-based APF will fill a disposable upper and lower gel tray; (2) the surfactant in the foaming agent has a cleansing action by lowering the surface tension. This also may facilitate the penetration of the material into interproximal surfaces where its action is most needed. The present findings showed that topical application of an APF foam significantly increased ($P < 0.001$) the F concentration in the outer 5-μm enamel, similar to that of an APF gel.

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Dr. Wei is a professor and head, and at the time of the study Dr. Hattab was a senior research assistant, children's dentistry and orthodontics,

[1] Grobler et al. 1981; Bruun et al. 1983; Hattab et al. 1987.

[2] Ericsson 1977; Clarkson and Wei 1982; Mellberg and Ripa 1983; Sluiter and Purdell-Lewis 1984.

[f] Oral B Laboratories Inc; Redwood City, CA.

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