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Influence of viscosity and surfactant on fissure penetration of dental fluoride gels in vitro

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Summary

In this in vitro study the influence of viscosity and surface tension of dental fluoride-containing gels, morphological characteristics of human and artificial occlusal fissures and the penetration of these fluoride gels into fissures is demonstrated. Self-prepared hydroxyethylcellulose gels with viscosities ranging from 75 to 5800 mPas containing 1.23% NaF are used. Sodium laurylsulphate was added to one group. While viscosity plays a secondary role in the penetration of the gels, surface tension and fissure morphology are very important. The shallow-wide type of fissure is filled by all of the gels. The deep-narrow type of fissure is penetrated only by gels containing sodium laurylsulphate.

Introduction

Modern preventive dentistry has achieved a significant reduction of caries due to the widespread use of fluorides. However, there are parts of the human dentition which are still sites of predilection of caries development. These include fissures in permanent and deciduous teeth as shown in epidemiological studies by Lewis and Hargreaves (1975) who described an increase of decayed occlusal surfaces in 6-year molars shortly after their emergence. Not all of the different galenic forms for fluoride application available in modern preventive dentistry proved to be effective against fissure caries. Fluoridated gels, containing acidulated phosphate fluoride (APF) or organic fluoride derivatives, seem not to be effective in fissures (Holm et al., 1984; Wright and Retief, 1984). The same inefficiency is observed for fluoride-containing mouthrinses and toothpastes (Fanning et al., 1971). A possible explanation for these findings can be the anatomical form of occlusal fissures. Scanning electron microscopic studies revealed an intricate system of pits, recesses and even tunnels in the enamel (Galil and Gwinnett, 1975a; Juhl, 1983). Fissures can have a depth of up to 1200 μm in human third molars with a width rarely exceeding a few 100 μm. Thus they form a good retention site for microbial plaque (Karring et al., 1974; Galil and Gwinnett, 1975b) and are not easily accessible to oral hygiene or preventive measures.

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There are alternatives to topical fluoridation for the prevention of fissure caries such as fissure sealing with enamel-bonded composite resins (Meiers and Jensen, 1984; Wright and Retief, 1984; De Craene et al., 1986). Large-scale fissure sealing, however, is not a realistic goal and also the cost-effectiveness of this therapy is questionable since it requires much treatment time and cooperation from the mostly young patients. Furthermore, the fluoridation of drinking water seems to be effective in reducing fissure caries, especially when fluoridated water is taken up during preeruptive enamel mineralisation (Bakker-Dircks, 1963). Unfortunately, in many countries fluoridation of drinking water has become a controversial political subject and many of these fluoridation projects have been abandoned. So fluoride application on an individual scale is still the most used preventive treatment in dentistry. If the effectiveness in reducing fissure caries can be enhanced, it could become a very effective therapy since it can be adapted to the individual patient's needs. One reason for the poor efficacy of these topical fluoridation products may be an incomplete penetration into occlusal fissures. However, published data on the penetration of fluoride gels into fissures are scarce. Taylor and Gwinnett (1973) and Wright and Retief (1984) described the penetration characteristics of fissure sealant composite resins. McCall et al. (1985) measured the macroscopic repartition of fluoride gels on tooth surfaces in vivo using gels containing plaque indicator on plaque-covered teeth, but the microscopical aspect of gel penetration into occlusal fissures is not yet studied. Therefore the aim of the present study is to evaluate the influence of viscosity and surfactant contents on the penetration of fluoride gels into fissures and to find out in which way these factors have to be varied in order to improve the penetration. The role of anatomical characteristics of fissures in the penetration of gels is also studied.

Materials and Methods

The fissure models were prepared from polymethylmethacrylate (PMMA) (Candulor, Switzerland) or cut from the occlusal surface of extracted human molars (Fig. 1). In order to approach the natural variation in fissure morphology (Thom, 1972; Braun, 1973; Fejerskov et al., 1973), two types of fissure were chosen: one having a deep-narrow and the other a shallow-wide form.

Preparation of the fissure model in PMMA

In order to facilitate the in vitro study of the influence of the fissure form on the penetration of a fluoride gel a laboratory-made fissure model in PMMA was prepared. Studies on the surface free energy of dental materials show that PMMA resembles pellicle-covered enamel very closely (De Jong, 1984). A piece of stainless steel matrix band (Dentaurum, Pforzheim, F.R.G.) was wrought into the desired fissure-like form and embedded in a 1.5 mm thick layer of dental modelling wax. A mould of dental stone was poured around wax and matrix band. After boiling out the wax, the remaining cavity was filled with PMMA resin under pressure. After the resin had been cured (8 h at 80 °C), the stone mould and the matrix band were removed, leaving a fissure in the block of PMMA.

Preparation of the fissure model in human enamel

A number of clinically sound extracted human molars were embedded in self-curing resin (Pekatray, Bayer F.R.G.) without covering the fissure area. Slices of 1.5 mm thickness were cut perpendicular to the main fissure (vestibulo-lingually) with a hard-tissue microtome (Leitz 1600, Leitz, Wetzlar, F.R.G.). Specimens with a deep-narrow fissure and with a shallow-wide fissure were selected.

The fluoride gels

The gels were prepared with Idrorammosan (Arion, Brussels, Belgium), a partially ethoxilated derivative of hydroxyethylcellulose as gel base. This product is similar to those used in most of the commercial fluoride gels (Braden and Perera, 1976). They contain 1.23% NaF and 0.01% fluorescein for a better contrast. Four gels having a viscosity of 75, 245, 1200 and 5800 mPas also contain sodium laurylsulphate (SLS), an anionic detergent. A second group of 4 gels with the same

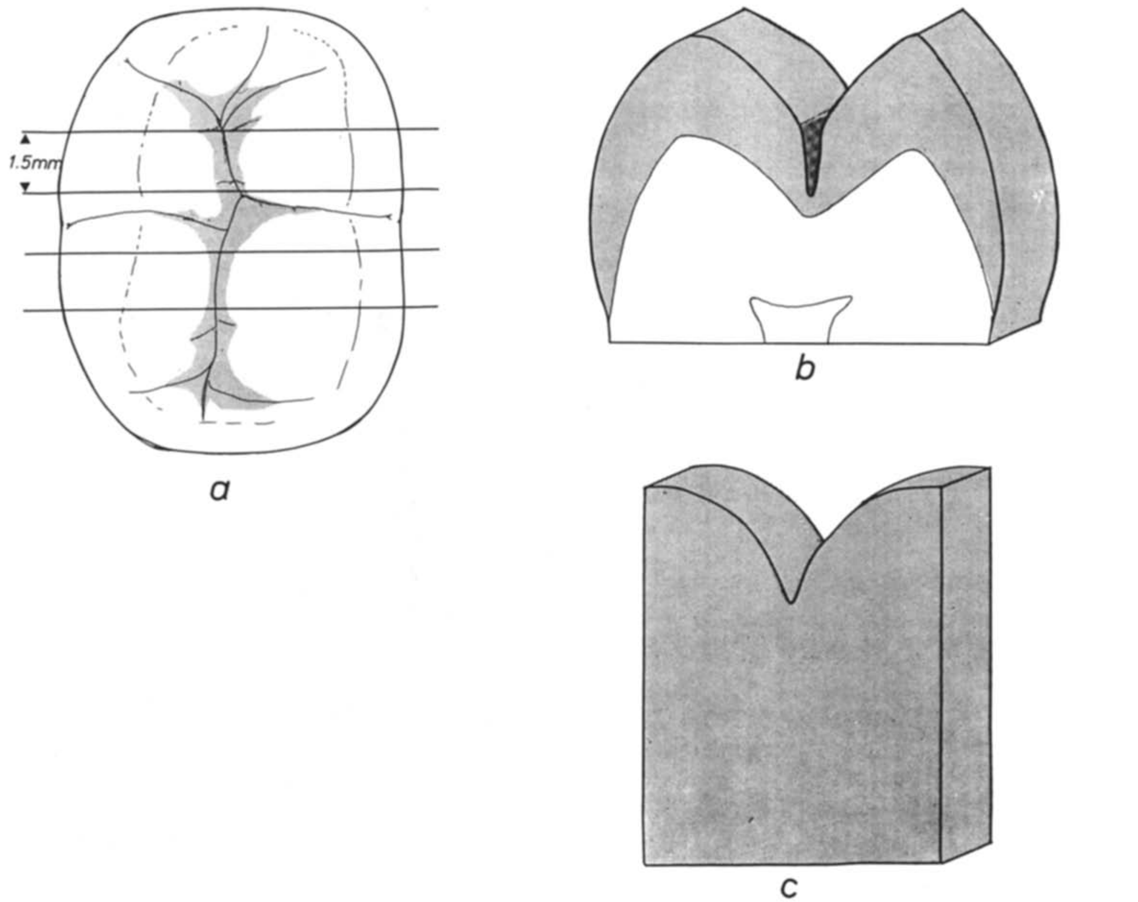

Fig. 1. View of an occlusal surface of a molar with main fissure area (shaded) and direction of the cuts (a), fissure model in human enamel with deep-narrow fissure (b), fissure model in PMMA with shallow-wide fissure (c).

viscosities as mentioned above containing 1.23% NaF and 0.01% fluorescein and no detergent served as a control group. The apparent viscosity is measured at 20 °C with a rotating cylinder viscosimeter (Haake RV with rotating cylinder MVI) at a shear rate of 37.4 s^{-1}.

The experimental set-up

The depth of penetration of the gels was measured with a microscope (Jenoptik GSM, Jena, G.D.R.) with a micrometer eyepiece at a magnification of 20 ×. The fissure models were attached with cyanoacrylate between two plates of perspex. One of the perspex plates had a hole for attaching the model to the microscope.

The fissure models were to be mounted in such a way that the gels could penetrate into the fissure by gravity. Therefore the long axis of the microscope was inclined 90° (Fig. 2). An injection device was used to avoid changes in viscosity due to pressure exerted on the gels during their appli-

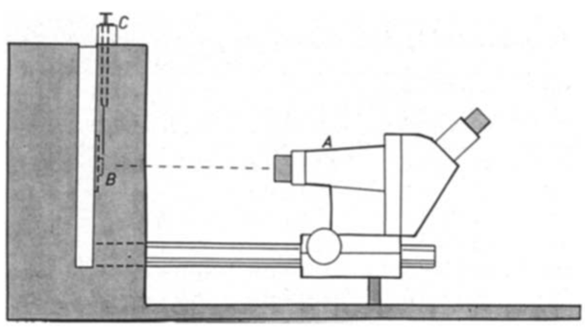

Fig. 2. Set up with inclined microscope. A = microscope; B = fissure model; C = gel injection device.

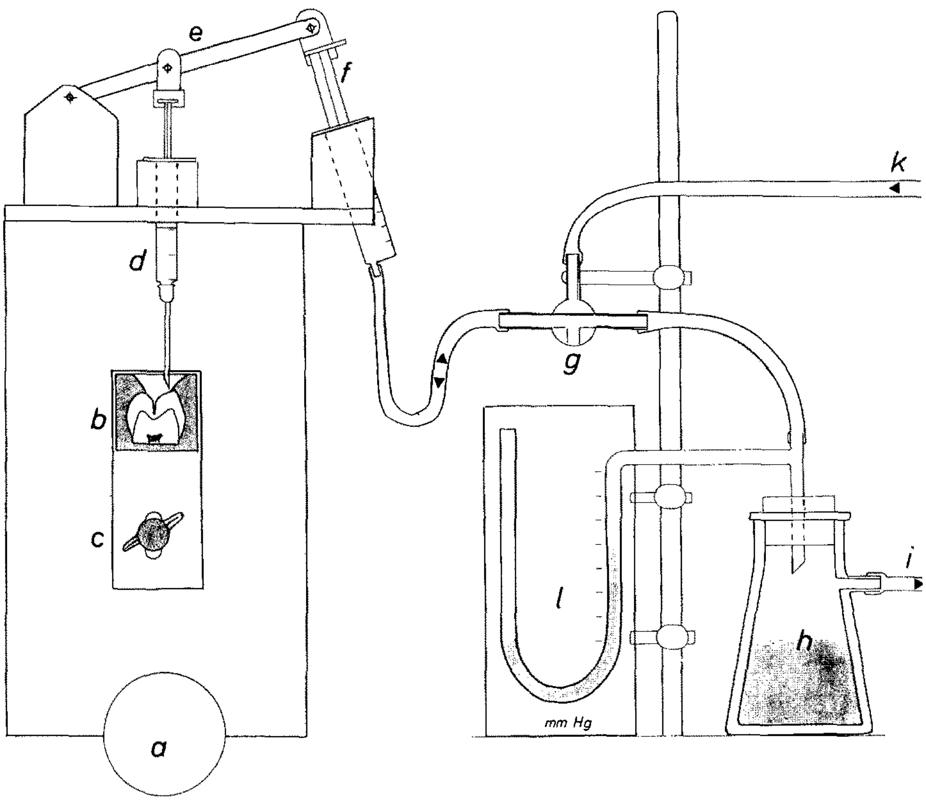

Fig. 3. The gel injection device. (a) microscope foot, (b) fissure model, (c) fixation of the model, (d) syringe containing the gel, (e) lever, (f) hydraulic plunger (syringe of 10 ml), (g) 3-way walve, (h) decanting bottle, (i) connection to vacuum pump, (k) pressurized water supply, (l) Hg manometer.

cation in the fissure. This system injected the gels with a reproducible pressure onto the cuspal slope of the fissure model (Fig. 3). Penetration depth of the gel into the fissure was recorded 10, 20, 30, 60, 120, 180 and 240 s after injection. The distance from the fissure bottom to the meniscus of the gel was measured, and subtracted from the total fissure depth. This absolute penetration depth was transformed into relative penetration depth in order to compare different fissure forms. After

TABLE 1

*Penetration (in %) of the fluoride gels with and without SLS into the **deep-narrow** fissure in human enamel*

Time (s)	η = 75 mPas		η = 245 mPas		η = 1 200 mPas		η = 5 800 mPas	
	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS
10	21.3 ± 4.1	69.3 ± 4.8	11.3 ± 3.0	38.0 ± 4.2	8.7 ± 1.6	28.7 ± 3.0	8.7 ± 3.9	25.3 ± 4.1
20	21.3 ± 4.1	74.0 ± 4.2	12.7 ± 3.0	43.3 ± 3.9	10.7 ± 3.3	33.3 ± 4.1	8.7 ± 3.9	28.7 ± 3.9
30	21.3 ± 4.1	87.3 ± 7.8	13.5 ± 3.0	51.3 ± 5.3	11.3 ± 3.0	44.0 ± 5.7	8.7 ± 3.9	33.3 ± 6.5
60	22.7 ± 3.3	100.0 ± 0.0	17.3 ± 4.1	63.3 ± 6.9	12.0 ± 4.4	54.7 ± 6.5	8.7 ± 3.9	42.7 ± 14.5
120	22.7 ± 3.3	100.0 ± 0.0	20.0 ± 4.1	95.3 ± 7.3	14.0 ± 4.2	66.7 ± 9.0	8.7 ± 3.9	51.3 ± 11.4
180	23.3 ± 3.0	100.0 ± 0.0	20.0 ± 0.0	100.0 ± 0.0	15.3 ± 3.0	90.0 ± 11.2	9.3 ± 3.3	51.3 ± 11.4
240	23.3 ± 3.0	100.0 ± 0.0	20.0 ± 0.0	100.0 ± 0.0	15.3 ± 3.0	100.0 ± 0.0	9.3 ± 3.3	51.3 ± 11.4

Values are mean ± S.D.

TABLE 2

Penetration (in %) of the fluoride gels with and without SLS into the ***shallow-wide*** *fissure in human enamel*

Time (s)	$\eta = 75$ mPas		$\eta = 245$ mPas		$\eta = 1\,200$ mPas		$\eta = 5\,800$ mPas	
	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS
10	97.0 ± 5.0	100.0 ± 0.0	87.0 ± 5.9	88.0 ± 8.5	75.2 ± 6.7	79.0 ± 3.3	63.7 ± 6.6	68.3 ± 5.8
20	100.0 ± 0.0	100.0 ± 0.0	93.0 ± 7.0	98.0 ± 3.1	83.0 ± 5.9	85.0 ± 3.3	68.3 ± 5.8	69.3 ± 6.6
30	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	88.0 ± 3.8	89.0 ± 4.5	73.2 ± 6.0	77.2 ± 12.6
60	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	94.0 ± 3.8	98.0 ± 3.1	79.0 ± 5.0	90.2 ± 15.6
120	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	99.0 ± 2.4	100.0 ± 0.0
180	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0
240	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0

Values are mean ± S.D.

each experiment the fissure model was rinsed with demineralised water and dried with air at room temperature.

Statistical processing of the results

The mean and standard deviations were calculated for the penetration in the fissure of each gel. The results are shown in Tables 1–4. Further evaluation of the results was done by an analysis of variance (ANOVA) and the Mann-Whitney *U*-test. ANOVA was chosen because the experimental design was based on a factorial scheme in which a number of variables are varied at the same time. Possible interactions between those variables had to be evaluated. In order to obtain a stable model of up to 3-way interactions, 6 replicas were performed for each experiment. The analyses were calculated with a computer using the statistical package for the social sciences (Nie et al., 1975). For the ANOVA the following factorial design was used: $2 \times 2 \times 2 \times 4$ (form: deep-narrow or shallow-wide; gels without or with SLS; fissure model in enamel or PMMA and 4 different viscosities). ANOVA was performed on this design using a multiple regression model. The regression equation can be formulated as follows:

$$
\begin{aligned}
y = {} & x_1 \cdot \nu + x_2 \cdot m + x_3 \cdot s + x_4 \cdot f \quad \text{(main effects)} \\
& + x_5 \cdot \nu \cdot m + x_6 \cdot \nu \cdot s + x_7 \cdot \nu \cdot f + x_8 \cdot m \cdot s \\
& + x_9 \cdot m \cdot f + x_{10} \cdot s \cdot f \quad \text{(2-way interactions)} \\
& + x_{11} \cdot \nu \cdot m \cdot s + x_{12} \cdot \nu \cdot m \cdot f + x_{13} \cdot \nu \cdot s \cdot f \\
& + x_{14} \cdot m \cdot s \cdot f \quad \text{(3-way interactions)}
\end{aligned}
$$

with ν being the viscosity, m the fissure material, f the fissure form, s the surfactant content, y the penetration and x the weight coefficient. This coefficient x expresses the effect of each variable

TABLE 3

Penetration (in %) of the fluoride gels with and without SLS into the ***deep-narrow*** *fissure in PMMA*

Time (s)	$\eta = 75$ mPas		$\eta = 245$ mPas		$\eta = 1\,200$ mPas		$\eta = 5\,800$ mPas	
	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS
10	20.8 ± 14.0	70.8 ± 35.9	15.0 ± 9.6	29.2 ± 17.0	17.2 ± 4.4	22.9 ± 12.7	13.8 ± 8.8	16.0 ± 7.4
20	21.7 ± 13.2	77.9 ± 33.0	17.1 ± 9.1	33.8 ± 20.1	19.6 ± 3.3	24.7 ± 13.0	15.8 ± 8.9	19.6 ± 9.1
30	22.5 ± 12.6	86.3 ± 33.7	17.5 ± 9.7	43.3 ± 32.9	20.8 ± 3.0	30.8 ± 14.0	17.5 ± 10.2	22.9 ± 10.9
60	23.8 ± 12.4	86.7 ± 32.7	20.4 ± 12.8	91.7 ± 20.4	22.5 ± 4.2	48.8 ± 25.0	19.2 ± 10.7	29.2 ± 12.5
120	25.8 ± 13.7	100.0 ± 0.0	22.1 ± 15.0	100.0 ± 0.0	24.2 ± 5.4	95.8 ± 10.2	22.5 ± 11.1	44.2 ± 11.9
180	28.8 ± 15.1	100.0 ± 0.0	22.1 ± 15.0	100.0 ± 0.0	24.6 ± 5.8	100.0 ± 0.0	23.3 ± 11.0	56.8 ± 12.6
240	28.8 ± 15.1	100.0 ± 0.0	22.1 ± 15.0	100.0 ± 0.0	27.5 ± 9.4	100.0 ± 0.0	24.6 ± 10.4	69.6 ± 9.3

Values are mean ± S.D.

or combination of variables on the penetration. The weight coefficient can have a positive (better penetration) or a negative (less penetration) sign and is expressed here in % more or less penetration. 4-way interaction was not calculated because it would lead to spurious results. Therefore it was considered as residual variance (background noise). The significance and the standard error of the weight coefficient x was calculated (F-test). ANOVA was performed at $t = 10$, 20, 30, 60, 120 180 and 240 s after injection. The values and signs of x are displayed in Fig. 8, the value, sign and standard error of x is given in Table 5.

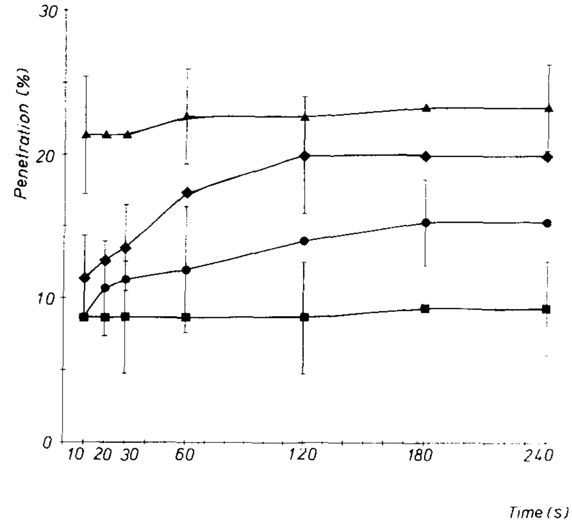

Fig. 4. Penetration of the fluoride gels without SLS into the deep-narrow fissure in human enamel. ▲———▲, 75 mPas without SLS; ◆———◆, 248 mPas without SLS; ●———●, 1200 mPas without SLS; ■———■, 5800 mPas without SLS. In order to simplify the figures, not all standard deviations are given (see Tables 1–4).

Results and Discussion

All results with standard deviations are given in Tables 1–4. Graphs are given for the fissures in human enamel only, since the results for the fissures in PMMA are similar.

In Fig. 4 the penetration is given for the fluoride gels without SLS into the deep-narrow fissure in human enamel. After an initial penetration of 10–25% gels do not penetrate much further. Low viscous gels penetrate significantly deeper ($P < 0.01$ according to the Mann–Whitney U-test) than the high viscous ones. On the contrary, fluoride gels with SLS, shown in Fig. 5, penetrate completely with the exception of the highest viscosity gel (5800 mPas). According to their viscosity, penetration is achieved between 60 s (75 mPas) and 240 s (1200 mPas). All gels with SLS show a significantly ($P < 0.01$) deeper penetration than the gels without SLS.

In the shallow-wide fissures, from which those in human enamel are shown in Figs. 6 and 7 gels penetrate very easily. The low viscosity gels achieve complete penetration within 10 s. The higher viscosity gels (1200 and 5800 mPas) penetrate at a somewhat slower rate. No significant differences can be demonstrated between gels with and without SLS.

The results of the penetration experiments show high standard deviations during the penetration phase of the gels. This can be explained by tena-

TABLE 4

*Penetration (in %) of the fluoride gels with and without SLS into the **shallow-wide** fissure in PMMA*

Time (s)	$\eta = 75$ mPas		$\eta = 245$ mPas		$\eta = 1200$ mPas		$\eta = 5800$ mPas	
	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS	without SLS	with SLS
10	100.0 ± 0.0	100.0 ± 0.0	93.6 ± 10.2	93.6 ± 15.7	50.0 ± 17.4	42.3 ± 19.9	23.1 ± 10.9	25.6 ± 6.3
20	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	97.4 ± 6.3	57.7 ± 12.6	53.8 ± 26.2	33.3 ± 10.5	32.0 ± 5.8
30	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	69.2 ± 13.8	61.5 ± 23.3	37.2 ± 11.3	39.7 ± 5.8
60	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	87.2 ± 15.9	78.2 ± 25.0	47.4 ± 14.9	47.4 ± 10.2
120	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	94.9 ± 7.9	61.5 ± 20.1	67.9 ± 18.5
180	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	80.8 ± 18.0	84.6 ± 14.6
240	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0

Values are mean ± S.D.

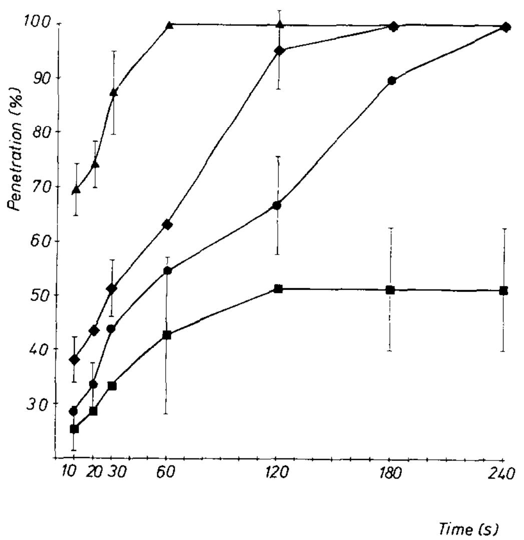

Fig. 5. Penetration of the fluoride gels with SLS into the deep-narrow fissure in human enamel. ▲———▲, 75 mPas with SLS; ◆———◆, 245 mPas with SLS; ●———●, 1200 mPas with SLS; ■———■, 5800 mPas with SLS. In order to simplify the figures, not all standard deviations are given (see Tables 1–4).

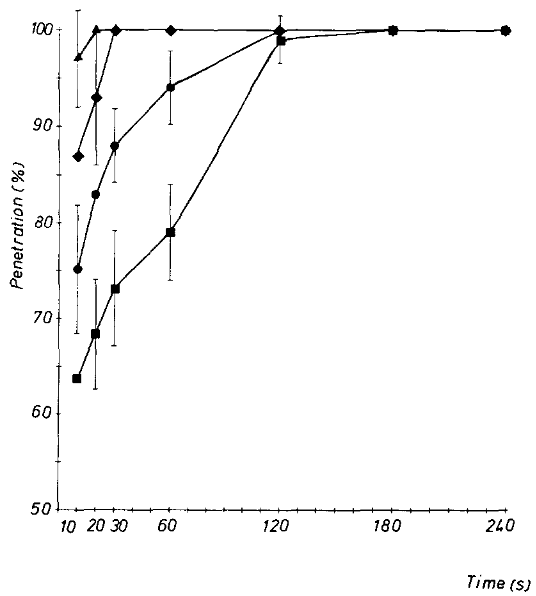

Fig. 6. Penetration of the fluoride gels without SLS into the shallow-wide fissure in human enamel. ▲———▲, 75 mPas without SLS; ◆———◆, 245 mPas without SLS; ●———●, 1200 mPas without SLS; ■———■, 5800 mPas without SLS. In order to simplify the figures, not all standard deviations are given (see Tables 1–4).

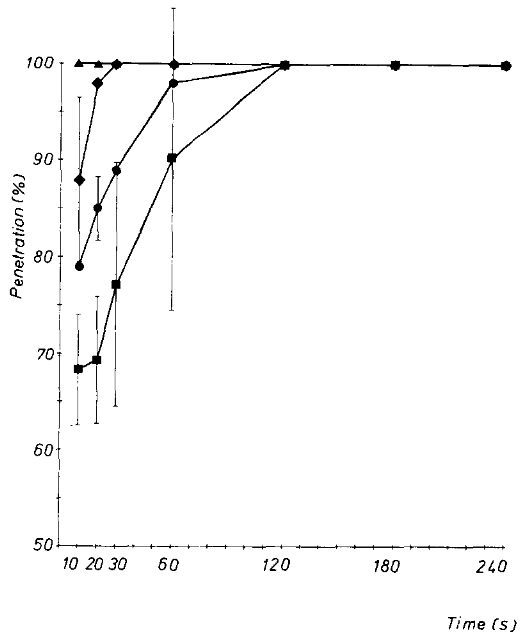

Fig. 7. Penetration of the fluoride gels with SLS into the shallow-wide fissure in human enamel. ▲———▲, 75 mPas with SLS; ◆———◆, 245 mPas with SLS; ●———●, 1200 mPas with SLS; ■———■, 5800 mPas with SLS. In order to simplify the figures, not all standard deviations are given (see Tables 1–4).

cious air bubbles, especially in high viscosity gels in the shallow-wide fissure and slight differences in wetting of the fissure wall, especially by the gels containing SLS. The results of the ANOVA performed on the penetration values for the different fissures, gels and surfactant content is given in Fig. 8. The weight coefficient x is given for different main effects and 2-way and 3-way interactions. The standard error of the weight coefficient is also given; x-values which were not significant in the F-test were neglected. A cumulative weight coefficient is given for all interactions of the variable viscosity. Positive weight coefficients mean a deeper penetration (in %) compared to the control group. Thus a positive influence can be seen for the variables fissure form (for the shallow-wide form) and surfactant content (for the gels with SLS). Higher viscosity gels have a negative weight coefficient.

To be effective in preventing fissure caries a fluoride gel should meet the following requirements:

TABLE 5

Value and S.E. for the weight coefficient x for different variables and interactions of variables

f = fissure form, s = surface tension, v = viscosity, m = fissure material, v_{cum} = cumulated x for viscosity S.E. = standard error, n.s. = not significant value for x

Time (s)	$f \pm$ S.E.	$s \pm$ S.E.	$v \pm$ S.E.	$v_s \pm$ S.E.	$v_f \pm$ S.E.	$v_{fm} \pm$ S.E.	$v_{cum} \pm$ S.E.
10	88.0 ± 5.4	46.3 ± 5.4	n.s	−12.9 ± 2.7	−15.6 ± 2.7	−12.9 ± 3.1	−41.4 ± 8.5
20	89.5 ± 5.3	50.7 ± 5.3	n.s.	−11.6 ± 2.6	−16.5 ± 2.7	−11.6 ± 3.1	−39.7 ± 8.4
30	90.2 ± 4.3	61.2 ± 5.5	n.s.	−10.0 ± 2.8	−18.6 ± 2.6	−11.2 ± 2.4	−39.8 ± 7.8
60	79.1 ± 5.5	76.0 ± 5.5	n.s.	0.0 ± 2.9	−19.8 ± 2.9	−12.0 ± 3.4	−31.8 ± 9.2
120	80.8 ± 4.6	84.0 ± 4.6	−2.4 ± 1.2	0.0 ± 2.3	−14.9 ± 2.3	−7.7 ± 2.7	−25.0 ± 8.5
180	76.6 ± 3.1	83.3 ± 4.0	−3.0 ± 1.5	1.9 ± 2.0	−11.3 ± 1.9	−3.7 ± 1.7	−16.7 ± 7.1
240	74.6 ± 3.4	82.5 ± 3.4	−5.0 ± 1.3	4.9 ± 1.7	−9.2 ± 1.7	−4.5 ± 2.0	−13.8 ± 6.7

(1) a high penetration ability into pits and fissures;
(2) a long contact time with the enamel in fissures and on smooth surfaces; and
(3) small residual quantities of fluoride remaining in the mouth after application.

The penetration ability is shown to be dependent on the fissure form, the surfactant content and the viscosity of the gel. These findings are in accordance with a theoretical formula which relates the penetration speed and depth of a viscous liquid into a capillary to variables such as viscosity, surface tension and liquid–solid contact angle (Arends, 1979). Gels having a viscosity of 1200 mPas or lower and containing a surface-active agent can penetrate even deep-narrow fissures. The shallow-wide fissure is easily penetrated by all gels. In these fissures, gels containing surface-active agents have no significant advantage over the habitually used gels without surface-active agents. In the deep-narrow fissure, penetration is limited at viscosities higher than 1200 mPas. However, very fluid gels are not easy to handle clinically, since they have to be applied in a tray. Thixotropic gels seem to have a certain advantage in this context (Braden and Perera, 1976).

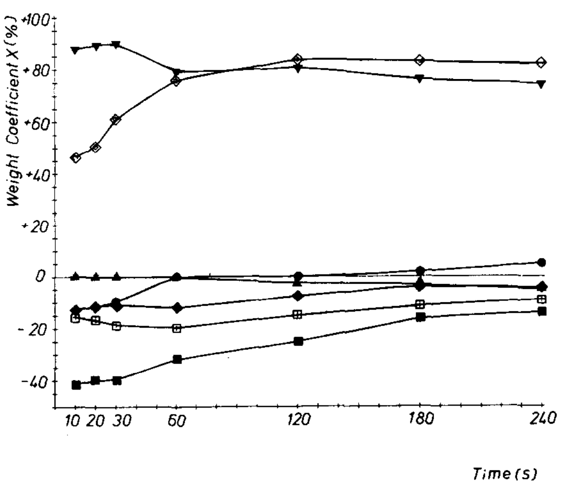

Fig. 8. The weight coefficient x for the different variables and interactions. *Main effects:* ▼——▼, fissure form; ◇——◇, surface tension; ▲——▲, viscosity. *Two way interactions:* □——□, viscosity and fissure form; ●——●, viscosity and surface tension. *Three-way interactions:* ◆——◆, viscosity, fissure form and fissure material. *Various interactions:* ■——■, cumulated effect of viscosity.

For in vivo application of such a gel the contents of a fissure have to be taken into account. Katada et al. (1982) observed enamel crystallites with low microhardness and concluded that fissures are shallower than formerly described. Karring et al. (1974) described plaque and microorganisms showing variable degrees of vitality, some of them mineralising (Galil and Gwinnett, 1975b). The latter finding could explain the results presented by Katada et al. (1982). Taylor and Gwinnett (1973) observed debris and pumice after cleaning the occlusal surface prior to fissure sealing. Zuhrt and Vierus (1967) demonstrated organic material, food debris and the remnants of the primary enamel cuticle. However, if a surface-active agent is added to a gel, plaque and debris can be displaced or penetrated much better. Plaque itself is no obstacle for the penetration of small ionised molecules (Melsen et al., 1979) and can even act as a fluoride reserve. It is shown that topical fluorides have a bacteriostatic effect on dental microbial plaque (Dolan et al., 1973; Loesche et al., 1975). This effect can be added to the remineralising effect of the fluorides. Benediktsson et al. (1982) showed that an APF-type fluoride gel has to be in contact for 2 to 6 hours to incorporate measurable amounts of fluoride into the enamel in vitro. Higher viscosity gels can remain longer in the fissure, but whether the contact time is sufficient to produce a measurable uptake of fluoride into the enamel of fissures is not yet determined in vivo.

Eisen and Le Compte (1985) determined the residual amounts of fluoride after application of fluoride gels of varying viscosities on the teeth. This residual fluoride can cause undesirable side-effects, especially in children or in patients who need frequent fluoride applications after irradiation, for instance. They concluded that, depending on the technique (lined or unlined trays, the use of aspiration or expectoration after application) and the viscosity of the gel, 1.7–7.4 mg fluoride of a total of 50 mg fluoride applied remained in the oral cavity. Although they did not give numerical values for the viscosity, they concluded that high viscosity gels yield the lowest amounts of residual fluoride.

The fissure form is a very important variable in penetration. This is also the only one that cannot be influenced by altering the gel formulation. Several studies have been published which related fissure form to dental caries susceptibility (König, 1963; Newbrun, 1959; Nagano, 1961; Feyerskov et al., 1976). These authors showed that in deep fissure the initial carious lesion starts under the level of the fissure entrance and not at its bottom. But the enamel layer between the fissure bottom and the dentine is very thin in deep fissures (Braun, 1973; Thom, 1972) and often less mineralised (Katada et al., 1982; Glenn et al., 1984), so that fluoridation with a surface-active gel will give more protection.

In this study the fissure material, PMMA or human enamel has nearly no effect on the penetration of the fluoride gels into fissures. The in vitro model can thus be regarded as reliable. It enabled us to choose a fissure form with well-defined geometrical characteristics. It is a good model to study penetration characteristics of gel vehicles in dead-ended capillaries, but in order to have data on surface interactions and fluoride uptake further research work will be performed on human enamel.

Conclusions

Fluoride gels with a viscosity of about 1200 mPas and favourable surface tension characteristics are shown to be suited best for clinical fluoride applications. They combine good penetration ability with a sufficient ease of handling for the practitioner and patient acceptability. Also, as is shown by Eisen and LeCompte (1985), less fluoride will be swallowed by patients. Further research is planned to evaluate to what extent commercially available gels meet the requirements stated in this paper.

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