In vivo uptake and retention of fluoride after a brief application of TiF_4 to dentin

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The purpose of this study was to examine the long-term retention of F and Ti in dentin after a brief application of 1% TiF_4. Six facets of exposed dentin in each of four beagle dogs were treated for 10 sec or 1 min with a 1% solution of TiF_4. Four control facets in a fifth dog were left untreated and extracted after 12 weeks. The TiF_4-treated teeth were harvested after 4, 8, and 22 weeks and analyzed for F and Ti with an electron microprobe. The F concentrations in dentin surfaces of specimens retained in the mouth for 4, 8, and 22 weeks were after the 10-sec treatment 0.48% ± 0.24, 0.51% ± 0.20, and 0.56% ± 0.20, respectively, and after the 1-min treatment 0.64% ± 0.20, 0.66% ± 0.18, and 0.71% ± 0.19. High concentrations of Ti were found at the specimen surfaces in all groups. None of the control specimens showed F or Ti contents above the detection limits for the method used. The results showed that a very brief application of 1% TiF_4 deposited high concentrations of F and Ti which were retained for at least 22 weeks. □ *Animal study; electron microprobe analysis*

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Titanium fluoride in aqueous solution as a caries-preventive topical agent has shown interesting properties when compared with other fluoride agents. Fluoride uptake in dentin surfaces after application of 3.4% TiF_4 for 4 min has been found to be as high as after treatment with fluoride varnishes and much higher than after application of a NaF solution (1, 2). Application of TiF_4 to enamel and dentin surfaces also results in the formation of a titanium-rich glaze (3–6), which presumably interacts with pellicle deposition and plaque formation, and hence with the caries process.

Previous in vivo studies in dogs have shown that the application period of the 3.4% TiF_4 solution may be reduced to 1 min and still result in a high uptake of F that is retained in the dentin surface for at least 21 weeks (2, 7). A subsequent in vitro study has indicated that the application period and the ionic strength of the applied TiF_4 solution can be further reduced and still enable considerable deposition of F and Ti in root dentin surfaces (8). A weaker solution (1%) would seem to be biologically more acceptable, and a further reduction of the application period to, for instance, 10 sec would make the application procedure more suitable for clinical use. Hence, the purpose of this study was to examine the long-term retention of fluoride and titanium after topical application in vivo of a 1% solution of TiF_4 for 10 sec and 1 min.

Materials and methods

Six teeth in each of four adult beagle dogs were used as experimental teeth, and four teeth in a fifth dog were used as controls. The dogs were littermates.

The operative procedures were carried out with the dogs under thiopental sodium (Pentothal® sodium) anesthesia. The buccal enamel of the canines and the maxillary first molars were ground with a water-flushed diamond point to expose dentin areas of 6–9 mm^2. The dentin surfaces were rinsed with a water spray and dried with blasts of air

before the fluoride solution was applied with cotton pellets in accordance with the following schedule: group 1: six surfaces in each of two dogs treated for 10 sec with 1% Ti_4 (0.32 M F); group 2: six surfaces in each of two dogs treated for 1 min with 1% TiF_4 (0.32 M F); and control group: four surfaces in one dog left untreated.

The dogs were maintained on a standard, soft laboratory diet with drinking water (0.7 ppm F) ad libitum.

The study design was approved by the Committee on Humane Care of Experimental Animals, and the dogs were maintained under the supervision of a veterinarian.

Two of the experimental teeth per dog were extracted after observation periods of 4, 8, and 22 weeks. The non-fluoride-treated teeth were extracted after 12 weeks.

The teeth were stored at 4°C and 100% humidity in glass vials containing wet cotton and a crystal of thymol until preparation for analysis. Longitudinal ground sections through the experimental surfaces of the teeth were prepared. Two sections approximately 200 µm thick were obtained from each tooth. The sections were placed in an ultrasonic cleaner for 2 min, dried at room temperature, and fixed to a specimen holder. They were then covered with a thin layer of carbon and analyzed in an Applied Research Laboratories electron microprobe that operated at 10 kV with a sample current on brass of about 60 nA.

Line scans of the electron beam, four scans per section, were made at right angles to the experimental dentin surface. The K_α radiation of F and Ti was registered. In addition, analysis of Ca was included to determine the exact position of the edge of the ground dentin surface. The concentrations were estimated assuming a linear relation between concentrations and intensities in the specimens as compared with those in the standard, after correction for background and dead time loss. The standards used were fluorapatite (38.94% Ca, 3.85% F) and biotite (1.83% Ti).

The zone of elevated fluoride concentration was estimated by noting the depth in the section at which the fluoride radiation was reduced to the normal background level.

For reasons discussed previously (9, 10), the concentrations recorded by electron microprobe analysis under the present operating conditions should be regarded as semiquantitative only. Further details concerning the analytical procedure have been given by Tveit & Tøtdal (10).

Results

The fluoride concentrations in the outermost part of the experimental dentin surfaces are shown in Table 1. The 1-min application resulted in only slightly higher F values than the 10-sec application. In both the 10-sec and the 1-min group no difference in fluoride content was found between specimens extracted after 4, 8, or 22 weeks. The line scans showed that the maximum values of F were at the surface and that the F content

Table 1. F concentration in dentin surfaces after application of 1% TiF_4 for 10 sec and 1 min, in accordance with the period of exposure to the oral cavity. Number of scans showing F values within each concentration range and mean values

Application period	Observation period	Percentage F in the dentin surface					
		<0.15	0.15–0.44	0.45–0.74	0.75–1.09	1.10–1.40	Mean*
10 sec	4 weeks	3	15	7	7		0.48 ± 0.24
	8 weeks		12	15	5		0.51 ± 0.20
	22 weeks	2	8	18	4		0.56 ± 0.20
1 min	4 weeks		3	22	7		0.64 ± 0.20
	8 weeks		5	20	7		0.66 ± 0.18
	22 weeks		1	21	9	1	0.71 ± 0.19

* Five analyses showing F concentrations below the detection limit were excluded from calculation of means. With these exceptions, each mean value represents 32 analyses.

dropped to a normal level at depths of 20–50 μm. There was a tendency to deeper penetration of F in the 1-min than in the 10-sec group. In both groups the depth of F penetration varied both within and between specimens. A typical electron microprobe scan is shown in Fig. 1. Five scans in the 10-sec group did not show fluoride concentrations above the detection limit (0.15%), presumably because of an error in specimen processing. Since the exact F concentration in these instances is unknown, the mean values obviously are not immediately comparable. In the control group none of the analyses showed F or Ti concentrations exceeding the detection limit.

Titanium was found on the specimen surface but not within the dentin. All Ti analyses showed values above the detection limit (Table 2). The Ti concentration varied considerably within and between specimens. Mean values in the 1-min group were about twice as high as in the 10-sec group. The Ti concentrations on the specimens were similar irrespective of the period of exposure to oral conditions.

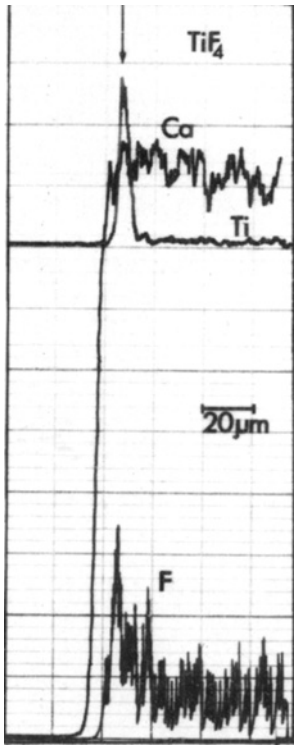

Fig. 1. Linear scan showing characteristic concentration profiles of calcium, fluoride, and titanium in a dentin surface treated with 1% TiF_4 for 10 sec and exposed to oral conditions for 22 weeks. Note elevation of the fluoride profile in a 20-μm-wide outer zone of the dentin and the high concentration of Ti at the surface. Arrow indicates the position of the specimen surface.

Discussion

The main interest of this in vivo study was the retention period of the F incorporated into the dentin and the longevity of the Ti glaze after a very brief application of a dilute solution of TiF_4. The results showed that the concentration of both elements within the surface layer of the exposed dentin and on the dentin surface remained nearly constant throughout the 22-week observation period. The chemical nature of the fluoride and titanium compounds retained is, however,

Table 2. Ti concentration on dentin surfaces after application of 1% TiF_4 for 10 sec and 1 min in accordance with the period of exposure to the oral cavity. Number of scans showing Ti values within each concentration range and mean values

Application period	Observation period	Percentage Ti on the dentin surface					
		0.40–0.99	1–2.99	3–4.99	5–6.99	7.00	Mean*
10 sec	4 weeks	8	18	5	1		2.06 ± 1.31
	8 weeks	4	21	6	1		2.23 ± 1.12
	22 weeks	7	24	1			1.74 ± 0.76
1 min	4 weeks	3	8	12	8	1	3.80 ± 1.85
	8 weeks	2	5	14	5	6	4.66 ± 2.63
	22 weeks	3	11	7	6	5	4.11 ± 2.45

* Each mean value represents 32 analyses.

not known and could not be assessed with the methods used.

The selection of ionic strength and application period of the TiF_4 solution was based on previous studies, which have shown that F is retained in dentin for at least 21 weeks after application of a 3.4% solution of TiF_4 for 1 min in dogs (7) and that, in vitro, application of a 1% solution for a period of only 10 sec results in considerable uptake of F and Ti (8). In a clinical study in which the caries-preventive effect of 1% TiF_4 applied annually was compared with that of acidulated phosphate fluoride (APF), a 1-min application of TiF_4 was found to be more effective than a 4-min application of APF (11). Thus, the results so far indicate that TiF_4 as an agent for topical fluoride application may be effective at a dilution factor that is biologically acceptable and may be used with a clinically convenient application period.

Acidic solutions may produce demineralization in tooth substances. One exception seems to be the TiF_4 solution, which, in spite of its low native pH (1% TiF_4, pH 1.5) seems to have a minimal demineralizing effect (7, 12). Nevertheless, the minimum application period and solution strength consistent with a sufficient fluoride uptake should be preferred for biologic reasons. Whereas mean concentrations were calculated from 32 registrations for each application period and period of oral exposure, the data were collected from a small number of teeth and animals. A statistical analysis of any trends shown is therefore of limited value. Although not significant, there was a tendency toward an increase rather than a reduction of the F concentration in the experimental surfaces with time. Such a trend could be explained by secondary uptake of F from the oral environment when a TiF_4 glaze is present on the tooth surface. Thus, McCann (13) has found that pretreatment of enamel with polyvalent cations results in higher retention of fluorides than the combined introduction of metal and F ions.

The possible effect of the Ti glaze on physicochemical properties of the dentin surface and the building up of pellicle and plaque is not known. In interpreting the results, it should also be kept in mind that the experimental surfaces were concave and that no abrasion due to hard food or oral hygiene procedures occurred. The application of these results to the clinical situation of exposed cementum or dentin, therefore, remains to be examined.

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