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Erosion-inhibiting effect of sodium fluoride and titanium tetrafluoride treatment *in vitro*

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The prevention of dental erosion with fluoride is still largely unknown territory. It was the aim of this study to determine the erosion-inhibiting effect of topical neutral 1% sodium fluoride (NaF) application and an application of a 4% titanium tetrafluoride (TiF_4) solution compared with no treatment. Ten bovine incisors were selected and three enamel samples prepared from each tooth. One sample from each tooth was assigned to one of three experimental groups. The experimental treatments were: no fluoride application (control); 4 min application of neutral 1% NaF gel; and 4 min application of 4% TiF_4 solution. All of the specimens were repeatedly exposed to 50 mM citric acid solution containing 0.4 mM $CaCl_2$, and 2.2 mM KH_2PO_4 at pH 3.0 over four consecutive days. The acid exposure was performed in intervals and the intensity was increased over the days of the experiment. Enamel dissolution was determined by calcium content measurement of the acid solution after exposure, using atomic absorption spectroscopy. A statistically significant erosion-inhibiting effect was found for both NaF and TiF_4 treatments compared with the control group from an erosion exposure time of 3 min. The reduction of calcium loss, however, was higher for the TiF_4-treated specimens than the NaF-treated. From 16 min of erosion exposure, the erosion-inhibiting effect was significantly stronger in the TiF_4 than the NaF group. The relative reduction of calcium loss compared with the control group remained stable for the TiF_4 group, whereas for the NaF group the relative reduction decreased with cumulative erosion time. It is concluded that topical TiF_4 application provides a potential treatment option in erosion prevention.

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In recent years, tooth wear has received increased attention in the dental community. It is suggested that tooth wear is becoming a growing problem among younger age groups (1–3). This early dental wear is described as mainly erosive wear, including both chemical etching of dental hard tissue (erosion) and mechanical wear (attrition and/or abrasion). It is assumed that a changing lifestyle might be responsible for this phenomenon, including a growing consumption of healthy but erosive food and juices, an increased access to acidic soft drinks, and improved oral hygiene attitude (4).

Although fluoride application is suggested as a treatment option in preventing erosion, the effectiveness of fluoride in reducing erosion has been questioned (5, 6). Moreover, the deposited calcium fluoride-like material (CaF_2) from topical fluoride application is supposed to dissolve readily in most acidic drinks (7, 8). Nevertheless, several *in vitro* studies have shown an erosion-inhibiting effect from topical fluoride treatment (9–11).

To date, most *in vitro* studies on the erosion-inhibiting effect of topical fluoride treatment have adopted the fluoride agents selected over the years for caries prevention: sodium fluoride (NaF), acidulated phosphate fluoride (APF), stannous fluoride (SnF_2), or amine fluoride (AmF). However, many other agents have been investigated for caries prevention. Some of these may be better tailored to the specific pathology of erosion. As long as 30 yr ago, Shrestha *et al.* (12) found that tooth specimens exposed to 0.01 M acetic acid (pH 4) showed less phosphate release when pretreated with tetrafluorides than with either 2% NaF, 8% SnF_2, or APF (1.23% F ions). Mundorff *et al.* (13) noted that during the application of titanium tetrafluoride (TiF_4) a glaze was formed on the tooth surface. They suggested that the solubility-reducing effect of TiF_4 might result from this phenomenon. Recently, Büyükyilmaz *et al.* (14) showed that the resistance of enamel exposed to 0.1 M HCl (pH 1.2) was greater for the specimens treated with TiF_4 than the untreated controls.

This laboratory study compared the erosion-inhibiting effect of topical fluoride treatment based on the deposition of CaF_2-like material using 1% NaF with treatment aimed at glaze formation using 4% TiF_4; both were used as a pretreatment of bovine enamel before periodic acid exposure.

Material and methods

Tooth specimens

Ten recently extracted bovine incisors were used for sample preparation. Three enamel specimens of approximately 3×3 mm were cut from the vestibular surface of each tooth. The samples were ground flat, embedded in acrylic resin and polished. One specimen from each tooth was assigned to one of three treatment groups. Before exposure, the size of the exposed enamel surface was measured individually using a stereomicroscope with measuring grid.

Fluoride treatment

The three treatment groups were: no fluoride treatment serving as a control; topical application of neutral 1% NaF gel (made by pharmacist on prescription) (NaF); and topical application of 4% TiF_4 solution (Aldrich Chemical Company, Milwaukee, WI, USA) (TiF_4). The NaF gel was applied to the surface and left undisturbed for 4 min The TiF_4 solution was applied in drops with cotton pellets. The drop was left undisturbed until the surface appeared dry. Additional drops were applied in the same manner until 4 min had elapsed. The controls as well as the fluoride-treated specimens were stored overnight in artificial saliva (Saliva Orthana; Pharmachemie, Haarlem, The Netherlands).

Erosion experiment

The acid exposure procedure was subsequently performed on four consecutive days. The erosive solution was based on pH as well as calcium and phosphate concentrations of soft drinks described by LARSEN & NYVAD (15), and consisted of a solution of 50 mM citric acid in water containing 0.4 mM $CaCl_2$, and 2.2 mM KH_2PO_4 at pH 3.0. Each specimen was immersed in 1 ml of this solution in a test tube at room temperature under gentle agitation. Acid exposure was performed in intervals and the intensity was increased over the days of the experiment: day 1, two times 0.5 min; day 2, three times 2 min; day 3, three times 3 min; day 4, three times 4 min The total erosion time was 28 min over 4 d. After each acid exposure, specimens were rinsed with 2.6 ml distilled water which was collected in the same tube. Subsequently 0.4 ml lanthanum oxide solution (final concentration 0.011 wt%) was added to the tube and its contents mixed well. Specimens were carefully blotted dry between exposures on each day, and after the final exposure they were blotted dry and stored in fresh artificial saliva. Before being exposed the next day specimens were rinsed with distilled water and blotted dry.

Calcium analysis

The calcium content of the test tube solutions was analysed by atomic absorption spectroscopy (model AS 90, Perkin Elmer Analytical Instruments, Shelton, CT, USA). Correcting for the calcium content of the experimental solution, which was regularly monitored throughout the experiment, the calcium loss from the enamel samples could be calculated. Lesion depth was estimated by using an average calcium content per unit volume for bovine enamel, correcting for exposed enamel area.

Statistical analysis

Two way ANOVA (treatment and tooth) was applied to analyse the treatment effects at the 11 time-points. The treatment effects are expressed as a Scheffé contrast which is tested at $\alpha = 0.005$ to adjust for multiple testing, including the corresponding 99.5% confidence interval.

Results

Table 1 shows the paired differences between the experimental regimens for mean calcium loss and estimated mean lesion depth after 11 cumulative erosive exposures. For calcium loss a statistically significant erosion-inhibiting effect was found for both NaF and TiF_4 treatment compared with the control group from an erosive exposure time of 3 min ($P < 0.005$). The reduction of calcium loss, however, was higher for the TiF_4-treated specimens than the NaF-treated specimens. From time-point 8 (i.e. 16 min of erosive challenge), the erosion-inhibiting effect was significantly stronger in the TiF_4 than the NaF group ($P < 0.005$).

Fig. 1 shows a graphical presentation of the mean calcium loss of each of the 11 separate erosive exposures for the three treatment groups. It can be seen that the first exposure of each day results in higher calcium loss than the other exposures that day. For NaF treatment the reduction of calcium loss compared with the control group decreases with the duration of the acid exposures, whereas for TiF_4 the reduction of calcium loss appears to be more stable. In Fig. 2 the cumulative effect of the erosive challenges is shown for lesion depth of the untreated and NaF- and TiF_4-treated specimens. Estimated lesion depth after 28 min of acid exposure was 4.4 μm (control), 3.6 μm (NaF), and 2.6 μm (TiF_4). The erosive effect shows a linear relationship with total acid exposure time for all three groups ($R^2 = 0.99$ for all three groups).

Discussion

The aim of the study was to investigate whether professional erosion prevention could be achieved using the same fluoride treatment as applied in caries prevention, or if an alternative fluoride agent would be preferable. This experimental study has shown that topical application of 4% TiF_4 was significantly more effective in protecting bovine enamel from initial erosive attacks than neutral 1% NaF. Furthermore it was found that the effect of the TiF_4 treatment appeared to remain stable up to a total etching time of 28 min.

It is well known that a solution of TiF_4 in itself is very acidic. In our experiment the solution had a pH of 1.5. As a result, tooth material dissolves during application. In a pilot study we used a cotton pellet to apply the TiF_4 solution with a rubbing action, as described by

Table 1

Paired difference for mean calcium loss and lesion depth of bovine enamel after immersion in 0.05 M citric acid, pH 3.0, between the control and NaF group, the control and TiF_4 group, and the NaF and TiF_4 group after 11 cumulative exposures

	Difference calcium loss (p.p.m.)			Difference lesion depth (μm)		
Cumulative erosive exposure	Control – NaF	Control – TiF_4	NaF – TiF_4	Control – NaF	Control – TiF_4	NaF – TiF_4
Day 1						
Time point 1 (0.5 min)	0.03 (−0.40 to 0.43)	−0.03 (−0.46 to 0.39)	−0.06 (−0.49 to 0.36)	0.00 (−0.13 to 0.13)	0.00 (−0.13 to 0.13)	0.00 (−0.13 to 0.13)
Time point 2 (1 min)	0.36 (−0.10 to 0.83)	0.31 (−0.15 to 0.76)	−0.05 (−0.51 to 0.41)	0.10 (−0.05 to 0.25)	0.12 (−0.03 to 0.27)	0.02 (−0.13 to 0.17)
Day 2						
Time point 3 (3 min)	0.46 (0.01 to 0.91)*	0.54 (0.09 to 1.00)*	0.09 (−0.36 to 0.54)	0.13 (−0.03 to 0.28)	0.20 (0.04 to 0.36)*	0.08 (−0.08 to 0.24)
Time point 4 (5 min)	0.79 (0.32 to 1.25)*	0.93 (0.46 to 1.39)*	0.14 (−0.32 to 0.60)	0.21 (0.04 to 0.39)*	0.33 (0.16 to 0.51)*	0.12 (−0.06 to 0.29)
Time point 5 (7 min)	1.11 (0.61 to 1.61)*	1.36 (0.85 to 1.85)*	0.25 (−0.25 to 0.75)	0.31 (0.12 to 0.50)*	0.48 (0.28 to 0.67)*	0.16 (−0.03 to 0.35)
Day 3						
Time point 6 (10 min)	1.45 (0.75 to 2.15)*	1.91 (1.21 to 2.62)*	0.47 (−0.24 to 1.17)	0.42 (0.16 to 0.68)*	0.67 (0.41 to 0.93)*	0.25 (−0.01 to 0.51)
Time point 7 (13 min)	1.82 (1.02 to 2.62)*	2.51 (1.71 to 3.31)*	0.69 (−0.11 to 1.49)	0.53 (0.25 to 0.82)*	0.87 (0.59 to 1.15)*	0.34 (0.05 to 0.62)*
Time point 8 (16 min)	2.14 (1.29 to 2.99)*	3.12 (2.27 to 3.97)*	0.98 (0.13 to 1.83)*	0.63 (0.33 to 0.93)*	1.08 (0.78 to 1.38)*	0.45 (0.15 to 0.75)*
Day 4						
Time point 9 (20 min)	2.12 (0.82 to 3.42)*	3.87 (2.57 to 5.17)*	1.75 (0.45 to 3.05)*	0.62 (0.20 to 1.04)*	1.21 (0.79 to 1.63)*	0.59 (0.17 to 1.01)*
Time point 10 (24 min)	2.36 (0.86 to 3.86)*	4.55 (3.05 to 6.05)*	2.19 (0.69 to 3.68)*	0.69 (0.22 to 1.17)*	1.42 (0.95 to 1.90)*	0.73 (0.25 to 1.21)*
Time point 11 (28 min)	2.55 (0.74 to 4.36)*	5.34 (3.53 to 7.16)*	2.79 (0.98 to 4.61)*	0.75 (0.18 to 1.31)*	1.68 (1.11 to 2.24)*	0.93 (0.36 to 1.49)*

Values are means with 99.5% confidence interval in parenthesis; $n = 10$ per group.
*Significant at $P < 0.005$

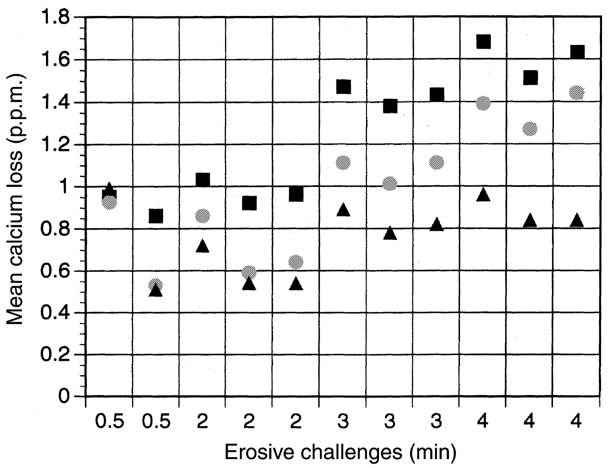

Fig. 1. Mean calcium loss (p.p.m) of each separate erosive exposure for the control (squares), NaF (circles), and TiF_4 (triangles) groups.

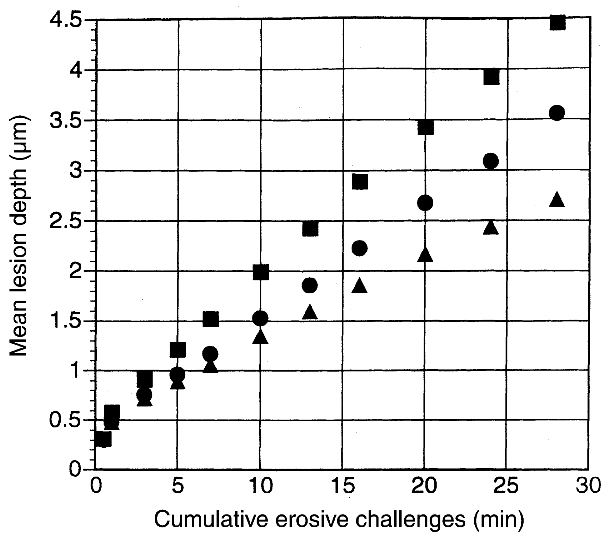

Fig. 2. Cumulative mean lesion depth (μm) against cumulative time of erosive exposure for the control (squares), NaF (circles), and TiF_4 (triangles) groups.

BÜYÜKYILMAZ *et al.* (14). Profilometry showed that this resulted in 6–8 μm loss of surface enamel. In the present study, therefore, no rubbing action was used and the solution was completely absorbed. In this way no material is removed by the fluoride application, which was confirmed by profilometry applied in the pilot study. Moreover, the formation of a surface layer or glaze was seen macroscopically. Contact profilometry in this longitudinal study was not feasible because it destructively alters the specimen surface.

It can be seen from Fig. 1 that the first acid exposure of each day resulted in a higher calcium loss than the two subsequent exposures. We assume that this is a result of the storage time and medium, allowing for remineralization of the softened surface enamel. The pattern is similar for control and experimental groups and does not significantly influence the cumulative calcium loss. For TiF_4 the reduction of calcium loss appears to be more stable than for the NaF-group, where the reduction appears to be smaller for the longer acid exposure times. However, with the present set-up it cannot be determined whether this is due to longer instantaneous exposure times or whether the cumulative acid exposure is 'depleting' the NaF-protection.

In the present study the pH of the acid challenge was 3.0, based on an average acidity of soft drinks. SHRESTHA *et al.* (12) found at a higher pH (4.0) that the dissolution in 0.01 M acetic acid was greater for enamel treated with either 2% NaF, 8% SnF_2, or APF (1.23% F ions) than treated with tetrafluorides. Moreover, the effect of the tetrafluorides lasted longer after repeated decalcifications, in particular using 1% TiF_4. WEI *et al.* (16) showed shallower depths from 0.5 M $HClO_3$ for TiF_4-treated specimens than for APF treatment at critical pH (5.5). BÜYÜKYILMAZ *et al.* (14) found higher microhardness values for the 4% TiF_4-treated samples than for the untreated controls after exposure to a very low pH (1.2), as in gastric acid. The results of the present experiment are in agreement with those studies.

TVEIT *et al.* (17) assumed that complexes were formed between TiF_4 and hydroxyapatite, based on a strong binding of the titanium compound and the oxygen atom of the phosphate group. MUNDORFF *et al.* (13) suggested that TiF_4 acted with enamel both chemically, by decreasing enamel solubility, and physically due to the formation of a protective glaze on the enamel surface. This physical protection would be an interesting aspect in erosion prevention since an erosive attack *in vivo* will generally be followed by a mechanical challenge from abrasion and/or attrition. Although the etching depth after 28 min, as calculated in this experiment (2.6 μm) far exceeded the estimated thickness of the glaze of about 0.1 μm, the glaze may have remained intact if it is porous, as has been suggested (14). This would then have resulted in a subsurface lesion instead of surface erosion. This phenomenon could not be checked by transversal microradiography (TMR) because the estimated depth of the lesion was lower than the detection limit of our TMR system (about 15 μm). Profilometry could not yield certainty since baseline profiles of the specimens were not available, again because this would have damaged the specimens. In future experiments these measurement options should be included where possible, for example using non-destructive optical profilometry.

It was concluded that topical TiF_4 application provides a potential treatment option in erosion prevention. The findings motivate further research into the erosion-inhibiting effect of TiF_4, in particular the effect on human enamel, the influence of lower TiF_4 concentrations, the duration of the protection established by TiF_4, and the effect of TiF_4 in relation to the mechanical aspects of erosive wear.

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References

1. Smith BG, Bartlett DW, Robb ND. The prevalence, aetiology and management of tooth wear in the United Kingdom. *J Prosthet Dent* 1997; **78**: 367–372.
2. Jaeggi T, Schaffner M, Burgin W, Lussi A. Erosionen und keilformige Defekte bei Rekruten der Schweizer Armee. *Schweiz Monatsschr Zahnmed* 1999; **109**: 1170–1182.
3. van Rijkom HM, Truin GJ, Frencken JEFM, König KG, van't Hof MA, Bronkhorst EM, Roeters FJM. Prevalence, distribution and background variables of smooth-bordered tooth wear in teenagers in The Hague, The Netherlands. *Caries Res* 2002; **36**: 147–154.
4. Zero DT. Etiology of dental erosion – extrinsic factors. *Eur J Oral Sci* 1996; **104**: 162–177.
5. Meurman JH, ten Cate JM. Pathogenesis and modifying factors of dental erosion. *Eur J Oral Sci* 1996; **104**: 199–206.
6. Imfeld T. Prevention of progression of dental erosion by professional and individual prophylactic measures. *Eur J Oral Sci* 1996; **104**: 215–220.
7. Larsen MJ. Prevention by means of fluoride of enamel erosion as caused by soft drinks and orange juice. *Caries Res* 2001; **35**: 229–234.
8. Larsen MJ, Richards A. Fluoride is unable to reduce dental erosion from soft drinks. *Caries Res* 2002; **36**: 75–80.
9. Davis WB, Winter PJ. Dietary erosion of adult dentine and enamel. *Br Dent J* 1977; **143**: 116–119.
10. Sorvari R, Meurman JH, Alakuijala P, Frank RM. Effect of fluoride varnish and solution on enamel erosion *in vitro*. *Caries Res* 1994; **28**: 227–232.
11. Ganss C, Klimek J, Schäffer U, Spall T. Effectiveness of two fluoridation measures on erosion progression in human enamel and dentine *in vitro*. *Caries Res* 2001; **35**: 325–330.
12. Shrestha BM, Mundorff SA, Bibby BG. Enamel dissolution: I. effects of various agents and titanium tetrafluoride. *J Dent Res* 1972; **51**: 1561–1566.
13. Mundorff SA, Little MF, Bibby BG. Enamel dissolution: II. action of titanium tetrafluoride. *J Dent Res* 1972; **51**: 1567–1571.
14. Büyükyilmaz T, Ögaard B, Rølla G. The resistance of titanium tetrafluoride-treated human enamel to strong hydrochloric acid. *Eur J Oral Sci* 1997; **105**: 473–477.
15. Larsen MJ, Nyvad B. Enamel erosion by some soft drinks and orange juices relative to their pH, buffering effect and content of calcium phosphate. *Caries Res* 1999; **33**: 81–87.
16. Wei SHY, Soboroff DM, Wefel JS. Effects of titanium tetrafluoride on human enamel. *J Dent Res* 1976; **55**: 426–431.
17. Tveit AB, Hals E, Isrenn R, Totdal B. Highly acid SnF_2 and TiF_4 solutions. *Caries Res* 1983; **17**: 412–418.