Fluoride release from NaF- and AmF-impregnated toothpicks and dental flosses in vitro and in vivo

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The aim of this study was to determine the fluoride release from toothpicks and dental flosses in vitro and in vivo, and to evaluate various approximal administration methods. In vitro, a total of 23 commercially available toothpicks and dental flosses and 3 prototypes impregnated with sodium fluoride (NaF), amine fluoride (AmF), or a combination of these two were tested. Fluoride release was determined for up to 24 h using an ion-specific electrode. A large variation was found between the products; most fluoride being released after 30 min. Generally speaking, toothpicks produced higher values than flosses. In vivo, the fluoride concentration in both treated and non-treated approximal areas was evaluated after using 2 different types of toothpicks and 4 dental flosses and after different application methods—such as a fluoride gel and fluoride solution. The mean fluoride concentration in oral fluid was up to 10 times higher at the treated sites than at the non-treated sites. Use of a fresh toothpick or a fresh piece of dental floss in each approximal space resulted in higher values compared with using one and the same toothpick/floss for the whole dentition. An interdental brush dipped in 0.2% NaF gel and a mouthrinse with 0.2% NaF resulted in elevated fluoride concentrations at the same level as when multiple toothpicks were used. To conclude, there are large variations in the fluoride release from various brands of fluoridated toothpicks and dental flosses. Treatment with a fluoridated toothpick or a dental floss can be expected to give elevated fluoride concentrations in the approximal area up to 60 min. Another interesting method for administering fluoride in the approximal area is to use an interdental brush dipped in fluoride gel. □ *Amine fluoride; dental flosses; fluoride gel; sodium fluoride; toothpicks*

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According to epidemiological data, the prevalence of approximal caries in the premolar and molar region is still high, especially among adolescents and adults (1–4). The number of dentate elderly is continuously increasing (5–7) and root caries, located for example in the approximal area, is an increasing problem (8–10).

Several studies have addressed the importance of good oral hygiene and the use of fluoride in order to prevent dental caries (11–13). There is no doubt that the use of fluoridated toothpaste is the single factor that has contributed most to the decline in dental caries since the mid-1960s (14–19). Other fluoride-containing products, such as varnishes, gels, mouthrinse solutions, and tablets, have also been found effective for caries-active patients (13, 20). In recent years, fluoridated toothpicks and dental flosses have been introduced onto the market (21, 22). Apart from their cleaning properties, the release of fluoride from these products may improve their caries-preventive effect and thereby reduce the level of dental caries in the approximal area (23).

The most commonly used fluoride sources are sodium fluoride (NaF) and sodium monofluorophosphate (MFP). Other fluoride compounds used in dental oral hygiene products are stannous fluoride (SnF_2) and amine fluoride (AmF). In addition to the fluoride effect, both these latter compounds have an antimicrobial effect (24). Apart from toothpicks and dental flosses, little is known about other vehicles administering fluoride into the approximal area. The aim of the present investigation was therefore to evaluate the release of fluoride from various NaF- and AmF-impregnated toothpicks and dental flosses in vitro and compare toothpicks and dental flosses with other methods of fluoride administration in the approximal area in vivo.

Materials and methods

In vitro study

An inventory was made of all available fluoridated toothpicks and dental flosses on the Swedish market. In addition, 3 prototypes manufactured by GABA International AG (Switzerland) were included in the study. A total of 12 toothpicks and 14 dental flosses, 26 products in all, were included in the study (Table 1).

Ten packages were randomly selected from the different toothpicks and dental flosses. From each box, one toothpick or 20 cm of floss was immersed in a Petri dish containing 10 mL of water and 1 mL of TISAB. In the case of Proxident Elastic Dental Floss, 10 cm of dental floss extended up to 20 cm was used. The dish was gently

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Table 1. Toothpicks and dental flosses included in the in vitro study. Brand name, manufacturer, fluoride compound, and fluoride concentration after release in water at 30 min and 24 h are given for each product. Data represent the mean ± *s* (standard deviation) ppm F for 10 packages for each product. Ranking according to the fluoride release at 30 min

Brand name	Manufacturer, country	Fluoride compound	Fluoride concentration (ppm)	
			30 min	24 h
Toothpicks				
Flossbrush	Dentac AB, Sweden	NaF	3.1 ± 0.2	3.5 ± 0.2
Jordan Dubbel	Jordan, Norway	NaF	6.6 ± 5.4	13.3 ± 9.2
Sanodent	Cederroth, Sweden	NaF	9.7 ± 8.0	14.4 ± 11.0
Jordan Enkel	Jordan, Norway	NaF	10.5 ± 16.3	14.7 ± 14.9
Proxident Plaststicka	Athena Nordic AB, Sweden	NaF	12.1 ± 14.4	14.4 ± 15.3
Blåvitt Fluor	Konsum, Sweden	NaF	13.1 ± 8.1	24.7 ± 0.1
TePe Björk[1,2]	TePe munhygienprodukter AB, Sweden	NaF	16.4 ± 2.2	47.8 ± 3.3
TePe Lind	TePe munhygienprodukter AB, Sweden	NaF	17.6 ± 5.1	41.8 ± 3.3
Butler	Butler, USA	NaF	18.4 ± 5.6	28.2 ± 7.1
Prototype A[1]	GABA International AG, Switzerland	AmF	22.3 ± 4.5	28.2 ± 3.7
TePe Björk Smal	TePe munhygienprodukter AB, Sweden	NaF	26.5 ± 4.6	36.8 ± 6.8
Proxident Trätandsticka	Athena Nordic AB, Sweden	NaF	37.8 ± 8.2	48.1 ± 9.7
Dental flosses				
Blåvitt Fluor	Konsum, Sweden	NaF	0.01 ± 0.03	0.02 ± 0.04
Jordan Fresh	Jordan, Norway	NaF	0.06 ± 0.08	0.05 ± 0.01
Jordan Easy Slide	Jordan, Norway	NaF	0.1 ± 0.1	0.1 ± 0.1
Colgate Total	Colgate, USA	NaF	0.4 ± 0.4	0.4 ± 0.2
Jordan Active Care	Jordan, Norway	NaF	0.4 ± 0.3	0.7 ± 0.3
elmex dental floss (old version)[1]	GABA International AG, Switzerland	AmF	0.7 ± 0.2	0.7 ± 0.1
Johnson & Johnson Dentotape[1,2]	Johnson & Johnson AB, Sweden	NaF	2.4 ± 0.2	3.6 ± 0.2
Dentosal	Dentosal, Sweden	NaF	4.6 ± 0.4	4.2 ± 2.3
Sanodent	Cederroth, Sweden	NaF	5.3 ± 2.4	5.9 ± 2.7
elmex dental floss unwaxed	GABA International AG, Switzerland	AmF + NaF	13.7 ± 2.6	14.7 ± 2.7
Proxident Elastisk Tandtråd	Athena Nordic AB, Sweden	NaF	28.3 ± 3.3	90.8 ± 5.4
elmex dental floss waxed	GABA International AG, Switzerland	AmF + NaF	35.2 ± 3.4	36.9 ± 3.3
Prototype B[1]	GABA International AG, Switzerland	AmF + NaF	57.5 ± 5.7	57.9 ± 5.9
Prototype C[1]	GABA International AG, Switzerland	AmF + NaF	76.8 ± 42.3	80.6 ± 42.1

[1]Used in Series I. [2]Used in Series II.

stirred at intervals. The fluoride concentration was then determined in the solution after 30 min and 24 h using an ion-specific electrode (ORION 96-09, Boston, Mass., USA).

In vivo study

Study design. Two different test series (here called Series I and Series II) were conducted. In Series I, 2 toothpicks and 4 dental flosses were tested. In Series II, 7 different methods were compared for administering fluoride to the approximal area. The study was approved by the Ethics Committee at Göteborg University (S 633-01) and informed consent was obtained from all subjects.

Subjects. In Series I, 6 healthy volunteers (5 women and 1 man), aged 42 ± 11 years and with a DMFT of 10 ± 8, were included. For Series II, 6 other healthy volunteers (4 women and 2 men), aged 45 ± 9 years and with a DMFT of 14 ± 5, were recruited. They all had a normal stimulated salivary secretion rate (2.1 ± 0.8 mL/min in Series I and 2.1 ± 1.0 mL/min in Series II). No glass ionomer fillings were found in the approximal posterior region where the treatment and sampling were carried out. All subjects were instructed not to use fluoride-containing products in the 48 h prior to each test occasion and not to eat or drink 1 h before the test.

Test products. In Series I, the subjects came to the laboratory 10 times in order to test 2 toothpicks (TePe Björk and Prototype A) and 4 dental flosses (elmex dental floss [old version], Johnson & Johnson Dentotape, Prototype B and Prototype C); 4 of these 6 products were tested in duplicate (TePe Björk, Prototype A, elmex dental floss [old version] and Johnson & Johnson Dentotape). The products were impregnated with NaF, AmF or NaF+AmF (Table 1). In Series II, each subject made 7 visits for laboratory testing: 1) a single toothpick (TePe Björk), 2) multiple toothpicks (TePe Björk), 3) a single dental floss (Johnson & Johnson Dentotape), 4) multiple dental flosses (Johnson & Johnson Dentotape), 5) an interdental brush (Mellanrumsborste; TePe munhygienprodukter AB, Sweden) dipped in 0.2% NaF solution (Dentan; Ipex Medical AB, Sweden), 6) an interdental brush (Mellanrumsborste; TePe munhygienprodukter AB) dipped in 0.2% NaF gel (Apoteksbolaget, Sweden), and 7) a mouthrinse with 0.2% NaF [control] (Dentan; Ipex Medical AB). For both series, at least 1 week passed between each test occasion. All prototypes were manufactured by GABA International AG, Switzerland.

Treatment. In Series I, the treatment was performed at 2 approximal sites, i.e. 45/46 and 25/26. The toothpick was first moistened in the mouth for a few seconds and then used for 1 min between 45/46. This was repeated with a fresh toothpick at 25/26. In a similar manner, a 20-cm-long piece of dental floss was first used for 1 min at 45/46 and then at 25/26. In Series II, the treatment was performed in all the approximal sites (a total of 11) in the upper jaw. One toothpick and one piece of dental floss (20-cm long) were used at all sites in methods 1 and 3. For methods 2 and 4, a fresh toothpick and piece of dental floss were used at each site. For methods 5 and 6, an interdental brush was dipped into the fluoride solution or fluoride gel for some seconds prior to inserting it into each site. In Series II, each site was treated for 10 s. Method 7 included a mouthrinse with 10 mL of 0.2% NaF solution for 1 min.

Sampling. One standardized triangular-shaped paper point (1.5 × 5 mm), cut from Munktell filter paper no. 1600 (Grycksbo Pappersbruk, Sweden), was inserted into the approximal area with a pair of forceps. The paper point, which sucks up approximately 4 μL, was kept in place for at least 20 s until it was soaked in saliva from the approximal area. It was then transferred to a 0.5-mL Eppendorf tube (covered with a lid) containing 200 μL of de-ionized water with 20 μL of TISAB III (Orion Research, Boston, Mass., USA). The samples were kept frozen until analysed. In Series I, the samples were taken from the 2 treated sites (45/46 and 25/26) and from 2 non-treated sites located next to the treated sites (46/47 and 26/27); they were obtained before treatment (baseline; 0 min) and 2, 5, 10, 30, 45, and 60 min after treatment. The samples were always collected in the following order: 45/46, 46/47, 25/26, and 26/27. Series II samples were taken from 4 of the 11 sites (16/15, 14/13, 23/24, and 25/26) before (baseline; 0 min) and 2, 10, 30, and 60 min after treatment. Thus, no sampling was carried out at 5 and 45 min. They were always collected in the same order, i.e. from the right to the left side.

Analysis of fluoride. After thawing, the tubes were kept in a refrigerator for 24 h, during which the absorbed fluoride was allowed to diffuse from the paper into the solution. Prior to analysis, the samples were thoroughly mixed by vibration for 10 s; 100 μL was transferred to a Petri dish and the fluoride concentration was analyzed using an ion-specific electrode, with the surface of the electrode placed in close contact with the solution. The detection level of fluoride was approximately 0.01 ppm.

Statistical analyses

The mean ± *s* (standard deviation) for each product analysed in vitro was expressed both as ppm and mM fluoride. For all in vivo results, only mM fluoride was used. In Series I, the mean values of the 2 treated and non-treated sites for each individual were calculated, after which the mean ± *s* for all test subjects was calculated. For the 4 products tested in duplicate, the mean of the 2 test series was calculated. The mean data of the 2 test sites, 6 individuals and 1–2 test series are presented in Figs 1 and 2. In Series II, the mean ± *s* of the fluoride concentration of each site and method was calculated. All the in vivo values were also transformed to logarithmic values. The area under the curve ($AUC_{0–60\ min}$) was calculated for each individual curve (on a non-logarithmic scale), after which the corresponding mean ± *s* was calculated for the treated and non-treated sites for the 6 methods (Series I) and for the 4 individual sites and the mean of the 4 sites for the 7 methods (Series II). Two-way analysis of variance (ANOVA) was used to test the significance of differences between the treatments. When the ANOVA rejected the multisample hypothesis of equal means, multiple comparison testing was performed with Fisher's PLSD. When comparing the duplicate tests (Series I), correlation coefficients (*r*) were calculated.

Results

In vitro

For the majority of toothpicks, most fluoride was released after just 30 min (Table 1). A wide range was found among the products (3.1–37.8 ppm fluoride; corresponding to 0.7–2.0 mM). Proxident Trätandsticka and TePe Björk Smal showed the highest fluoride release of all 12 toothpicks and Flossbrush and Jordan Dubbel the lowest.

The commercial flosses resulted in lower values than the toothpicks (Table 1). With the exception of Proxident Elastisk Tandtråd, most fluoride was released after just 30 min and only a small additional release was found after 24 h. In the case of Blåvitt Fluor, Jordan Fresh and Jordan Easy Slide flosses, little or no release of fluoride was found after 24 h (0.01–0.1 ppm fluoride; corresponding to 0.001–0.003 mM fluoride). The two prototypes B and C, both containing a mixture of AmF and NaF, gave higher values than the commercially available flosses. However, a large standard deviation was found for Prototype C.

In vivo—Series I

Toothpicks. The mean fluoride concentrations ± *s*, given both as absolute and logarithmic values after using the 2 types of toothpicks at the treated and non-treated sites, are shown in Fig. 1 (upper figures). No difference was found when comparing the upper and lower jaw (data not shown). The fluoride concentrations were still above baseline after 60 min, especially at the treated sites. In the case of the treated site, TePe Björk resulted in a numerically higher concentration at 2 min when compared with Prototype A with a peak value of 9.7 ± 4.7 mM fluoride for TePe Björk and of 5.5 ± 2.4 mM fluoride for Prototype A. An opposite trend was found for the non-treated sites, i.e. higher fluoride values for Prototype A. From 20 min and onwards, the fluoride profiles were

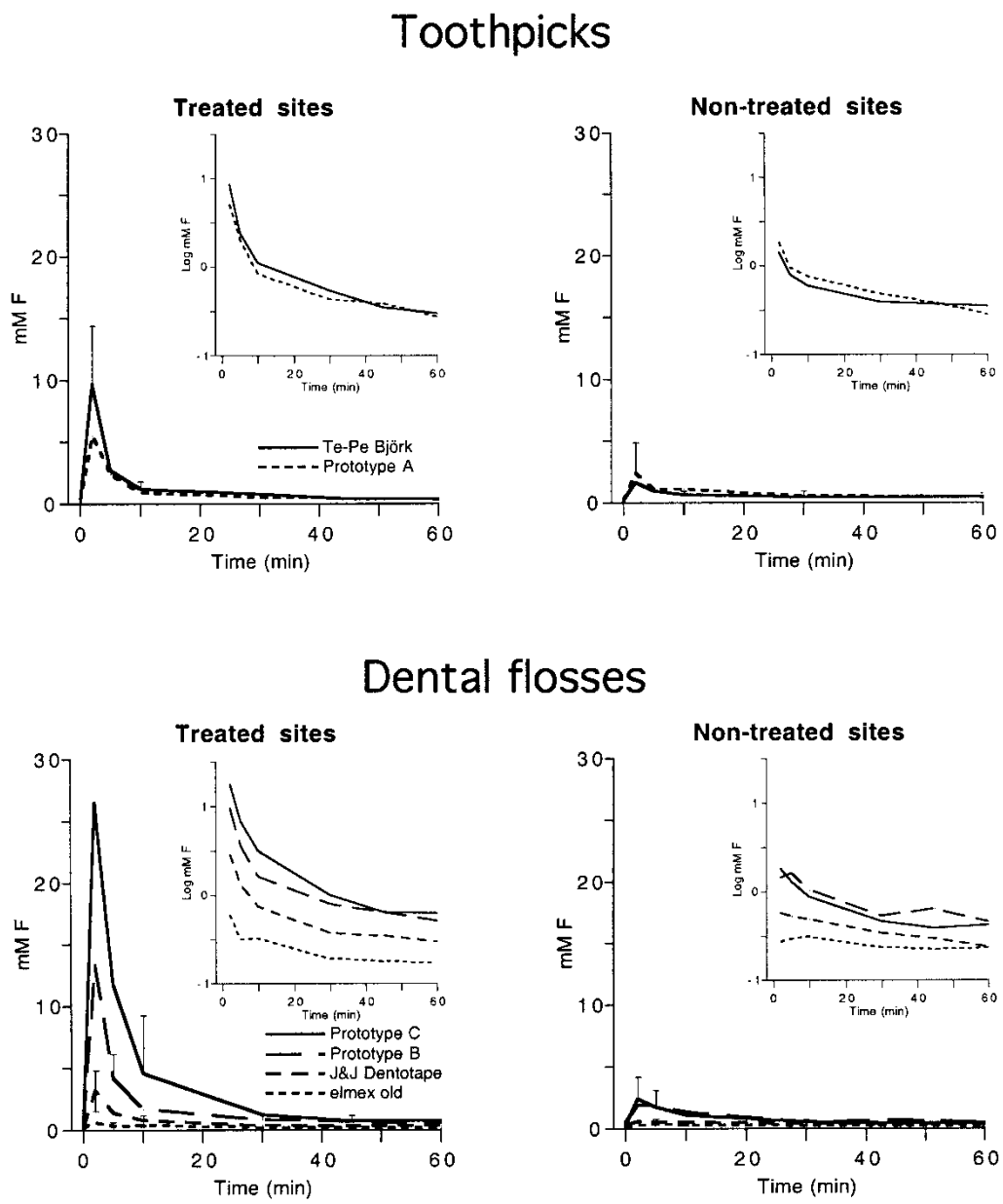

Fig. 1. Fluoride concentration (mM) in the approximal area after using 2 toothpicks (upper figure) and 4 dental flosses (lower figure) tested in Series I (given both as absolute and logarithmic values). Results from the treated (left) and non-treated (right) sites. Mean values of 6 individuals. (J&J Dentotape = Johnson & Johnson Dentotape; elmex old = elmex dental floss (old version)).

more or less identical for the 2 products. No statistically significant differences were found between the 2 types of toothpicks either at the treated or the non-treated sites.

Dental flosses. The data for the 4 dental flosses are shown in Fig. 1 (lower figures). Here, too, the peak values were found at 2 min. Prototype C resulted in the highest values. At 60 min, the mean fluoride concentrations were higher for all products compared with the baseline values. There were several statistically significant differences among the 4 flosses at different time-points, especially at 2 min (data not shown). The mean $AUC_{0-60\ min}$ are shown in Fig. 2 and also here there were differences between some of the products.

Toothpicks vs dental flosses. When comparing the $AUC_{0-60\ min}$, the 2 toothpicks resulted in higher values than the 2 flosses, elmex dental floss (old version) and Johnson & Johnson Dentotape, but lower or similar values to the 2 floss prototypes. However, the data have not been compared statistically.

Treated vs non-treated sites. In both Series I and Series II the fluoride concentration was several times higher at the treated than at the non-treated sites (from 2 up to 10 times

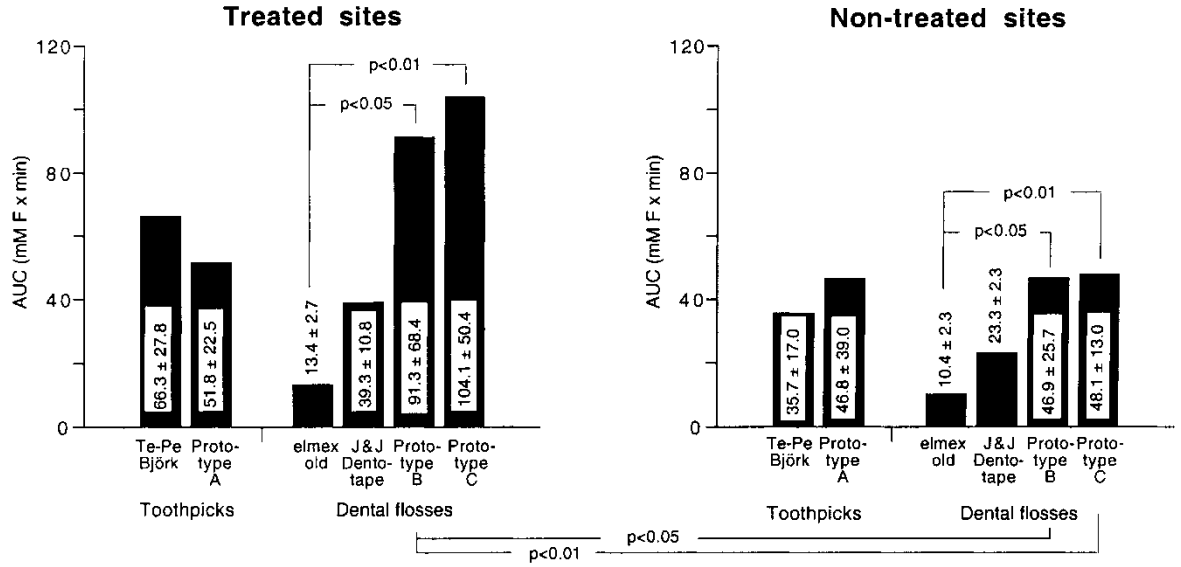

Fig. 2. Fluoride concentration in the approximal area expressed as $AUC_{0–60\ min}$ (mM F × min) at the treated (left) and non-treated (right) sites after using 2 different toothpicks and 4 dental flosses tested in Series I (the values are based on those given in Fig. 1). Mean values of 6 individuals. The statistical analyses have been carried out comparing the toothpicks and dental flosses with each other. (J&J Dentotape = Johnson & Johnson Dentotape; elmex old = elmex dental floss (old version)).

at 2 min). When comparing the $AUC_{0–60\ min}$, there were several statistically significant differences between the 2 types of sites in Series I (Fig. 2).

Duplicate samples. A comparison of the results for the 4 products carried out in duplicate revealed similar results between the 2 test series (data not shown). The correlation coefficients (r) for the peak fluoride concentration at 2 min varied between 0.16 and 0.67 ($r = 0.49$ when all the products were considered together). The corresponding correlation values at 60 min ranged between 0.34 and 0.85 (mean $r = 0.47$). Moreover, in the case of the $AUC_{0–60\ min}$, a high correlation was found; r ranged between 0.44 and 0.78 (mean $r = 0.55$).

In vivo—Series II

The mean $AUC_{0–60\ min}$ values and the statistically significant differences for the various methods are shown in Fig. 3. The interdental brush dipped in 0.2% NaF gel resulted in the highest approximal fluoride concentration, followed by the 0.2% NaF mouthrinse and both ways of using toothpicks. Dental flosses resulted in the lowest AUC values.

On comparing the 4 sites, a stepwise reduction in fluoride concentration from site 16/15 to 25/26 was observed after use of a single toothpick and a single dental floss (Fig. 4). More consistent fluoride levels were found for the 4 sites for the other 5 methods. For site 16/15, treatment with the interdental brush dipped in 0.2% NaF gel, the mouthrinse with 0.2% NaF and toothpick resulted in significantly higher values when compared with dental flosses ($P < 0.05$ or $P < 0.01$). This was also the case for site 14/13 ($P < 0.01$ or $P < 0.001$). In the case of site 25/26, only multiple toothpicks, the interdental brush dipped in 0.2% NaF gel and the mouthrinse with 0.2% NaF differed significantly from the 2 dental floss methods ($P < 0.05$, $P < 0.01$, or $P < 0.001$).

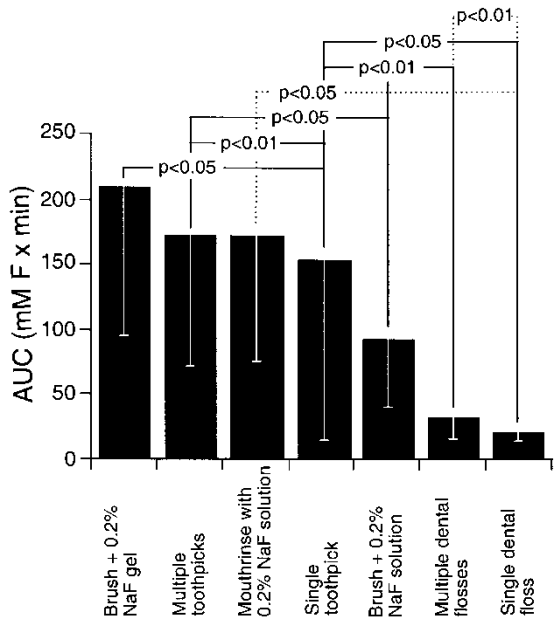

Fig. 3. Fluoride concentration in vivo expressed as $AUC_{0–60\ min}$ (mM F × min) for the 7 methods tested in Series II. Mean values ± s (standard deviation) of 6 individuals and 4 sites/individual. (Brush = interdental brush).

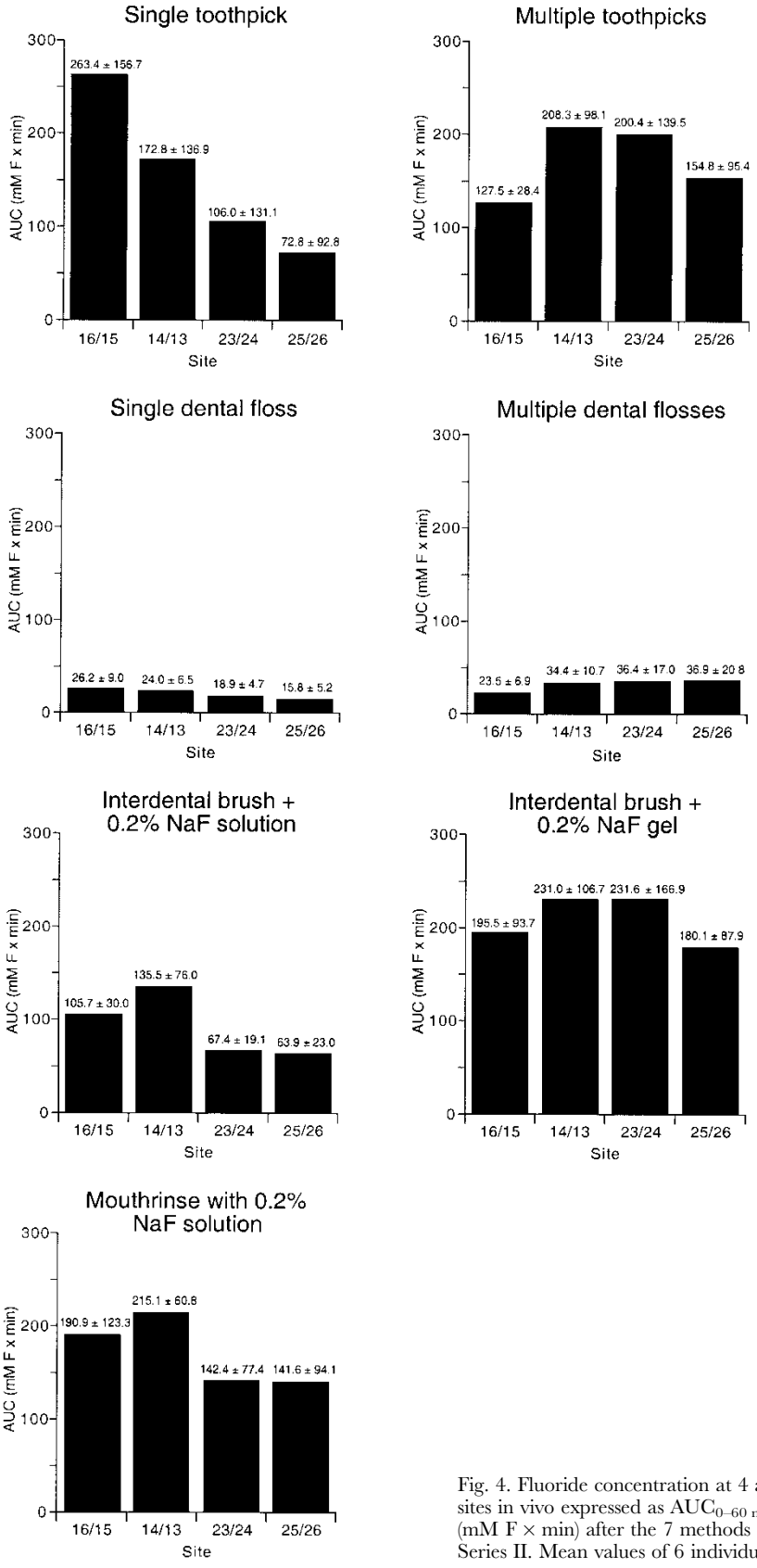

Fig. 4. Fluoride concentration at 4 approximal sites in vivo expressed as $AUC_{0-60\ min}$ (mM F × min) after the 7 methods tested in Series II. Mean values of 6 individuals.

Discussion

The in vitro series showed that there was great variation in the release of fluoride from the different products and that some of the flosses did not release any or at most a negligible amount of fluoride (0.06 ppm F). Most fluoride was released after just 30 min in the case of both toothpicks and flosses. An exception was the new floss Proxident Elastisk tandtråd, which is made of an elastic material in which NaF is incorporated at an early phase of the manufacturing process. Apart from the two prototype flosses, all the toothpicks released more fluoride than the flosses. One may speculate as to whether this is due to a low fluoride content in the flossies or to difficulties associated with the fluoride release.

Up to now, it has been difficult to impregnate dental flosses with a large amount of fluoride. Since the completion of this study, two new dental flosses (elmex dental floss waxed and elmex dental floss unwaxed) have been introduced on to the market. These products are based on the prototypes included in the present study and show similar high fluoride release. Another example of a new floss with a high concentration and quick release of fluoride is Proxident Elastisk Tandtråd.

Previous studies of toothpicks have shown that both birch and lime toothpicks have a high capacity to absorb as well as release NaF (21, 25–26). It has been suggested that chemical reactions between fluoride and various organic and inorganic substances present in the wood may protract or inhibit release of the fluoride that is retrieved (21). However, in a previous study carried out in our laboratory, around two-thirds of the total fluoride content was released after 24 h in vitro (25). In the present study, we used a method of analysis in which the toothpick and dental floss are soaked in distilled water and 10% TISAB. It has been shown that the fluoride release may differ depending on the media used (21). A higher fluoride release has been found for NaF-impregnated toothpicks soaked in water compared to saliva, while the opposite has been observed in the case of toothpicks impregnated with AmF.

The in vivo series revealed that all test products resulted in elevated fluoride concentrations in oral fluid from the approximal area throughout the entire test periods. Thus, there were still higher fluoride values at 60 min after treatment compared to baseline. When comparing the 6 products with each other, there was a small range at 60 min in contrast to 2 min, which was the first sampling occasion. The highest fluoride concentration in overall terms was found for the 2 prototype flosses impregnated with NaF + AmF, which resulted in higher values than the prototype toothpick (containing AmF). However, in the case of commercially available products, the toothpicks resulted in higher fluoride levels compared with the dental flosses. This matches the in vitro experiments. The present data also correspond well with those of a previous study in which the approximal fluoride content after using fluoride-impregnated toothpicks was comparable to other fluoridated products, such as dentifrice, mouthrinse solution and a tablet (22).

It has been suggested that the interproximal fluoride level is about 2–4 times higher than the salivary level after fluoride treatment (22). The well-known elimination curve after fluoride exposure described by Weatherell et al. (27), with a fast initial phase followed by a slower elimination, was also clearly demonstrated in the present study. The oral fluoride clearance is associated both with product-related and with individual-related factors. Regarding the latter, the salivary flow rate and the volumes of saliva in the mouth before and after swallowing are of great importance (28). It should be pointed out, however, that the sampling procedure itself reduces the fluoride concentration in the approximal area when a paper point is used. This has been demonstrated by Kashani et al. (22), who found higher approximal fluoride values when the first sampling did not take place until 10 or 20 min after the treatment. However, the high correlation of the duplicate samples obtained in the present study indicates that there is a high reproducibility of the method.

It is interesting to note that elevated fluoride concentrations were found not only at the treated sites, but also at the adjacent non-treated sites. The fluoride concentration at the non-treated sites displayed smaller variation between the products than the concentration at the treated sites. However, when comparing the treated and the non-treated sites, 5–45% lower values were found for the non-treated sites. The possibility that a treated site on one side of the dentition will influence the other side is regarded as small. It is well known that there is a limited migration of fluoride from one side of the mouth to the other and that the oral cavity, in relation to fluoride distribution, can be regarded as 'compartmentalized' (29). In a previous study evaluating a fluoride-containing chewing gum, we observed that the fluoride concentration in saliva is strongly dependent on the side on which the subjects chewed (30).

The products tested in this study were impregnated with different fluoride compounds, i.e. [NaF, AmF, or NaF+ AmF]. To date, the most commonly used fluoride source incorporated into oral hygiene products has been NaF. However, AmF, which was used in all 3 prototypes in the present study, has been found to result in elevated fluoride levels in saliva after using toothpaste and a mouthwash (31). It is also well known that AmF possesses an antimicrobial activity against cariogenic bacteria (24, 32) as well as an anticaries effect (33).

An interesting finding from the in vivo series was the difference in fluoride release in relation to application method. As expected, a gradual reduction in fluoride concentration was found during treatment of the 11 sites when using one and the same toothpick or dental floss. The use of multiple toothpicks and dental flosses overcame this problem, but may not be considered as a realistic way of using the products. For a fully-dentate subject, it may instead be advisable to start to use the toothpick or floss at the sites where the need of fluoride is highest, often in the molar-premolar region. It is therefore important to advise

subjects at high risk of caries that they optimize their use of approximal cleaning tools impregnated with fluoride in order to obtain a good caries-preventive effect. The best results in overall terms for fluoride application in the present study were found for an interdental brush dipped in 0.2% NaF gel for some seconds prior to inserting it into each site. This gave higher values than dipping the brush in 0.2% NaF solution. This difference can be explained by the higher retention of the gel in the approximal area in comparison to the solution. A mouthrinse with 0.2% NaF was also found to be effective.

To conclude, the present study showed that both fluoridated toothpicks and dental flosses give elevated fluoride concentrations up to 30 min after use. However, there is great variation in the release of fluoride from various brands, especially among the fluoridated dental flosses. As an alternative to using a fluoridated toothpick or fluoridated floss, an interdental brush dipped in 0.2% NaF gel may be an interesting method of administering fluoride into the approximal area in caries risk patients.

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