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Fluoride Release and Recharge of Orthodontic Adhesives after Exposure to Sodium Fluoride Mouthwash: An In Vitro Study

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Abstract

Aim

Fluoride-releasing orthodontic adhesives with the ability to recharge fluoride may help prevent white spot lesions during orthodontic treatment. This study aimed to evaluate the effect of sodium fluoride (NaF) mouthwash on the fluoride release and recharge capacity of orthodontic adhesives over a 28-day period.

Methods

In this in vitro study, 36 extracted sound human maxillary premolars were randomly assigned to three groups (n=12): No-Mix composite resin (Ortho Organizer Everest, USA) for bracket bonding, resin-modified glass ionomer (RMGI; GC Corporation, Tokyo, Japan) for bracket bonding, and sound enamel without bracket bonding (control). Each group was further divided into two subgroups (n=6) based on the storage condition: daily exposure to 250 ppm sodium fluoride (NaF) mouthwash or artificial saliva. After bracket bonding, each tooth was individually immersed in artificial saliva and incubated at 37°C. Cumulative fluoride release was measured using a spectrophotometer (InoLab® Multi 9420, WTW, Germany) on days 1, 7, 14, and 28. Following the 28-day period, the fluoride recharge capacity of the materials was evaluated by daily exposure to 250 ppm NaF mouthwash for one minute, after which fluoride release was measured again using the same protocol. Data were analyzed using Kruskal–Wallis, repeated-measures ANOVA, Friedman, and post hoc Tukey tests at a significance level of 0.05.

Results

Fluoride release from all groups showed a significant decreasing trend over the 28-day period, with the highest levels observed on day 1 ($P<0.001$). Daily exposure to 250 ppm sodium fluoride mouthwash significantly increased fluoride release from both orthodontic adhesives compared with artificial saliva, particularly during the early evaluation periods. On day 1, a significant difference in fluoride release was observed among the groups ($P<0.001$), with sound enamel demonstrating higher fluoride levels than the adhesive groups. A similar significant difference was noted on day 7 ($P<0.001$). However, these differences diminished over time, and no statistically significant differences were detected among the groups at 14 days ($P=0.278$) or 28 days ($P=0.061$). Both No-Mix composite resin and RMGI demonstrated fluoride recharge capability following NaF exposure, resulting in higher fluoride release compared with specimens not exposed to fluoride. Over time, the fluoride release patterns of the two adhesives became comparable, with no significant long-term difference between them.

Conclusion

Daily exposure to sodium fluoride mouthwash appeared to enhance fluoride uptake and subsequent release in both No Mix composite resin and RMGI specimens. Although differences were observed at early time points, fluoride release patterns between the two adhesives became comparable over time. These findings suggest a potential fluoride recharge capability in both materials; however, the clinical relevance of these results should be interpreted with caution and may require further investigation.

Keywords: Composite resins, Dental bonding, Glass-ionomer, Sodium fluoride.

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Background

Dental caries is an infectious disease caused by bacterial colonization, followed by demineralization of the inorganic part of the tooth and degradation of the organic matrix (1). *Streptococcus mutans* is the main microorganism involved in the development of dental caries (2,3). Although the prevalence of dental caries has declined in many developed countries, it is still on the rise in some developing countries (4).

Prevention is the most efficient strategy to control dental caries. Fluoride can prevent the progression of carious lesions and enhance remineralization. Thus, fluoride mouthwash plays an important role in reducing *Streptococcus mutans* counts and in subsequent caries prevention as an adjunct to mechanical plaque removal (5–7). Several strategies have been proposed to increase fluoride uptake and enhance remineralization of demineralized tooth structure, such as water fluoridation and topical application of various fluoride forms (8–11). Fluoride has two main effects: (I) prevention of demineralization of sound enamel, and (II) enhancement of enamel remineralization through participation of fluoride in the tooth enamel structure (12).

Orthodontic brackets bonded to the tooth surface provide a suitable space for bacterial colonization. Also, orthodontic treatment alters the oral microbial flora and promotes caries development (13,14).

At present, various fluoride-releasing cements are available on the dental market, including glass-ionomer and resin-modified glass-ionomer (RMGI) cements (15). Such products release fluoride and can be recharged by topical use of fluoride compounds to sustain fluoride release (15).

Application of fluoridated compounds can trigger fluoride ion release and enhance the recharge of fluoride-releasing orthodontic cements, providing gradual release until the next application of such compounds. This process can be effective in preventing demineralization around orthodontic brackets (16–20). Considering the above, this study aimed to evaluate the effect of sodium fluoride mouthwash on the fluoride release and recharge capacity of two orthodontic adhesives over a 28-day period.

Methods

This in vitro study was conducted on 36 sound human maxillary premolars extracted for orthodontic treatment. The study protocol was approved by the Ethics Committee of Mashhad University of Medical Sciences (code: 961785).

The sample size was calculated using the formula for comparing two means based on data from a previous similar study (21), with a confidence level of 95% (α=0.05) and statistical power of 95% (β=0.05). The minimum required sample size was estimated to be four specimens per subgroup; however, to increase the accuracy and reliability of the results, the sample size in each subgroup was increased to six.

The teeth were randomly divided into three groups (n=12 per group). Standard edgewise orthodontic brackets (Dentaurum, Ispringen, Germany) were bonded to the teeth with either No-Mix composite resin (Ortho Organizer Everest, USA) in group 1, or resin-modified glass-ionomer cement (RMGI, GC Corporation, Tokyo, Japan) as a positive control in group 2. In group 3, no brackets were bonded, and no adhesive was applied (sound enamel group).

For bracket bonding in groups 1 and 2, the buccal surfaces of the teeth were cleaned with pumice paste, properly brushed, rinsed with deionized water, and dried.

In group1 (No-Mix composite), the teeth were etched with 37% phosphoric acid (Merck, Darmstadt, Germany) for 20 seconds, washed, and dried. Only the bracket bonding area was etched. According to manufacturer's instructions, the primer was applied by a brush to the base and the tooth surface, then the bracket was bonded at the center of the tooth crown. The entire surface of the bracket base was covered with composite resin; then the bracket was firmly pressed against the enamel, and any excess composite resin was removed from the surrounding area.

For bracket bonding with RMGI, no enamel etching was performed, and the bracket was bonded to intact enamel. To standardize the quantity of RMGI, the entire surface of the bracket base was covered with RMGI. After bracket bonding, excess RMGI was removed by a scaler, and curing was performed from the mesial, distal, occlusal, and gingival surface for 10 seconds (total of 40 seconds) by a light-curing unit (SCS JR C137, Foshan SCS Medical Instrument, Foshan, China) at a distance of 1 cm.

Finally, all tooth surfaces were coated with nail varnish, leaving a window 1 mm larger than the bracket base exposed.

Preparation of Artificial Saliva and Demineralizing Agent

For the preparation of artificial saliva, 0.111 g of calcium chloride (1 mM), 0.156 g of sodium dihydrogen phosphate (1 mM), 2.05 g of sodium chloride (35 mM), and 2.05 g of sodium acetate (15 mM) were mixed and brought to 1000 mL with deionized water. Next, the pH of the solution was adjusted to 6.7–7.3 by adding KOH.

For the preparation of demineralizing solution, 2.2 mM $CaCl_2.2H_2O$, 2.2 mM KH_2PO_4, and 50 mM CH_3COOH were used. KOH was then added to adjust the pH to 4.5 (15).

Exposure to Sodium Fluoride Mouthwash (NaF)

Each group was randomly divided into two subgroups (n = 6 per subgroup). Random allocation was performed using a computer-generated random number sequence by a researcher who was not involved in the measurement procedures to minimize allocation bias.

In subgroup A, the teeth were not exposed to any fluoride-containing compound.

In subgroup B, the teeth were exposed to NaF mouthwash (Oral-B, Weynbridge, UK). They were immersed in 2 mL of NaF mouthwash containing 250 ppm fluoride for 1 minute daily for a total of 28 days. They were then rinsed with deionized water and dried before returning to artificial saliva.

As mentioned earlier, bracket bonding was not performed for group 3, and NaF mouthwash was applied to sound enamel.

Next, the teeth in each subgroup were placed in capped plastic vials containing 6 mL of artificial saliva at 37°C. Also, all teeth were immersed in the demineralizing solution for 6 hours a day to simulate the intraoral environment.

Measuring the Amount of Released Fluoride

The cumulative fluoride release was measured using a spectrophotometer (InoLab® Multi 9420, WTW, Germany) on days 1, 7, 14, and 28. For this purpose, teeth with brackets bonded using the respective adhesive were individually immersed in separate glass vials containing artificial saliva and incubated at 37°C. At each evaluation time point (days 1, 7, 14, and 28), the artificial saliva from each vial was collected and stored at −20°C until analysis. Prior to measurement, 1 mL of total ionic strength adjustment buffer (TISAB) was added to each saliva sample to prepare it for fluoride analysis. This solution was prepared by mixing 1 M sodium chloride, 0.25 M acetic acid, 0.75 M sodium acetate, 0.001 M sodium citrate, and also 2% cyclohexyline dinitrilotetracetic acid as a chelating agent for metal ions (to eliminate all ions present in the saliva except for fluoride to eliminate their confounding effect). Next, 8 concentrations of 0.1 to 10 ppm fluoride were transferred to the spectrophotometer for reading to ensure accuracy. Subsequently, artificial saliva without any specimen was used as the blank to calibrate the spectrophotometer prior to fluoride measurement.

Data were analyzed by SPSS 16 (SPSS Inc., IL, USA). The Shapiro-Wilk test indicated non-normality in some groups. Thus, the cumulative amount of fluoride ions after 28 days was compared between the groups by the Kruskal-Wallis test. Repeated-measures ANOVA, Friedman, and post hoc Tukey tests were applied for inter-group comparisons at different time intervals. The level of significance was set at 0.05.

Results

Comparison of the four time points based on the type of adhesive and fluoride product subgroup:

Artificial Saliva (No Fluoride) Subgroups

Table 1 shows the amount of released fluoride at 1, 7, 14, and 28 days in terms of the type of adhesive in the artificial saliva subgroup. The highest mean amount of released fluoride was recorded on day 1 and the lowest on day 28 in all groups of RMGI, No-Mix, and sound enamel. The amount of released fluoride differed significantly across time points in all groups ($P<0.001$ for all). In all groups, the amount of released fluoride decreased significantly over time ($P<0.05$).

In the RMGI group, the mean amount of released fluoride at 28 days was significantly lower than that at day 1 ($P<0.001$), day 7 ($P=0.012$), and day 14 ($P=0.019$). Also, the mean amount of released fluoride at 14 days was significantly lower than that at day 1 ($P=0.003$) and day 7 ($P=0.038$).

In the No-Mix composite resin group, the mean amount of released fluoride at 28 days was significantly lower than that on days 1 ($P<0.001$) and 7 ($P=0.044$). Also, the mean amount of released fluoride at 14 days was significantly lower than that at 1 day ($P=0.044$).

In the sound enamel group, the mean amount of fluoride released at days 14 ($P=0.031$) and 28 ($P=0.001$) was significantly lower compared with day 1.

NaF Mouthwash Subgroups

Table 2 shows the amount of released fluoride at 1, 7, 14, and 28 days, by type of adhesive, in the NaF mouthwash subgroups. The highest mean

amount of released fluoride was recorded on day 1, and the lowest on day 28 in all groups. The amount of released fluoride differed significantly across time points in all three groups (P<0.001 for all).

In all groups, the amount of released fluoride decreased significantly over time (P<0.05).

In the RMGI group, the amount of released fluoride significantly decreased over time, with significant differences between all the time points (P<0.05) except between 14 and 28 days (P=0.135).

In the No-Mix group, the amount of released fluoride significantly decreased at 28 days compared with 1 (P=0.002) and 7 (P=0.010) days.

In the sound enamel group, the amount of released fluoride decreased significantly over time, with significant differences between all the time points (P<0.001).

Table 1. Amount of released fluoride (ppm) at 1, 7, 14, and 28 days based on the type of adhesive in the artificial saliva subgroup (n=6 at each time point)

Group (adhesive type)	Time (day)	Mean (PPM)	Std. deviation	Minimum	Maximum	Median	Friedman test
RMGI	1	83.97	15.54	66.60	104.50	84.41	F*=14.02 P<0.001
	7	77.94	35.57	50.70	144.70	63.85	
	14	44.20	15.31	25.08	61.70	49.20	
	28	12.09	8.41	0.00	24.78	12.40	
No-Mix composite resin	1	128.80	30.64	75.51	159.00	139.28	X^2_F =18.00 P<0.001
	7	90.73	31.07	60.90	149.10	87.16	
	14	46.49	14.33	19.19	57.50	52.92	
	28	10.29	13.62	0.00	34.30	5.75	
Sound enamel without a bracket	1	3.64	2.60	0.90	7.53	2.86	X^2_F =16.74 P<0.001
	7	1.99	2.18	0.00	5.10	1.04	
	14	1.08	1.73	0.00	4.50	0.45	
	28	0.57	1.24	0.00	3.10	0.05	

*Repeated-measures ANOVA

Table 2. Amount of released fluoride (ppm) at 1, 7, 14, and 28 days based on the type of adhesive in NaF subgroup (n=6 at each time point)

Adhesive type	Time (day)	Mean (PPM)	Std. deviation	Minimum	Maximum	Median	Friedman test
RMGI	1	118.26	23.02	97.04	158.70	114.75	F*=45.53 P<0.001
	7	73.41	7.97	65.19	87.01	72.72	
	14	42.84	17.71	24.04	73.10	37.71	
	28	25.39	15.58	6.50	50.06	23.27	
No-Mix composite resin	1	112.79	38.53	72.51	164.70	110.85	X^2_F=16.40 P=0.001
	7	80.67	16.84	59.22	103.70	78.31	
	14	38.97	27.01	12.62	84.34	29.26	
	28	7.17	15.30	0.00	38.14	0.00	
Sound enamel without a bracket	1	92.19	7.07	82.40	102.10	91.96	F*=68.85 P<0.001
	7	57.81	39.39	11.4	125.7	54.35	
	14	32.23	7.79	21.70	42.79	33.11	
	28	17.26	12.31	0.00	34.97	17.42	

*Repeated-measures ANOVA

Comparison of Different Adhesive Types at Each Time Point

Table 3 compares the amount of released fluoride between the three groups at each time point.

On day 1, the highest and lowest mean amounts of released fluoride were observed in the sound enamel and RMGI groups, respectively. The mean amount of released fluoride was significantly different between the three groups (P<0.001). Pairwise comparisons of the groups revealed that on day 1, the mean amount of released fluoride in the sound enamel group was significantly higher than the RMGI (P=0.001) and No-Mix (P<0.001) groups.

On day 7, the highest and lowest mean amounts of released fluoride were found in the No-Mix and sound enamel groups, respectively. The mean amount of released fluoride was significantly different between the three groups (P<0.001). On day 7, the mean amount of released fluoride in the sound enamel group was significantly higher than in the RMGI (P=0.001) and No-Mix (P=0.004) groups. No other significant differences were found (P>0.05).

On day 14, the highest and lowest mean amounts of released fluoride were observed in the sound enamel and No-mix groups, respectively. The mean amount of released fluoride was not significantly different between the three groups (P=0.278).

On day 28, the highest and lowest mean amounts of released fluoride were observed in the RMGI and No-Mix groups, respectively. The mean amount of released fluoride was not significantly different between the three groups (P=0.061).

Artificial Saliva Subgroups

According to Table 4, the highest and lowest fluoride release occurred in the No-Mix and sound enamel groups on days 1, 7, and 14, respectively. The amount of released fluoride differed significantly between the adhesive groups at 1 (P<0.001), 7 (P=0.002), and 14 (P=0.004) days.

The difference in the amount of released fluoride was not significant between the adhesive groups at 28 days (P=0.082).

Pairwise comparisons of the groups on day 1 showed that the mean amount of released fluoride in the sound enamel group was significantly lower than in the other two groups (P<0.001 for all comparisons). Also, the value in the RMGI group was significantly lower than that in the No-Mix group (P=0.003). At 7 and 14 days, the mean amount of released fluoride in the sound enamel group was significantly lower than in the other two groups (P<0.001 for both). No other significant differences were found.

Table 3. Comparison of the amount of released fluoride among the groups at each time point

Time (Days)	Group	Mean (PPM)	Std. deviation	Minimum	Maximum	Median	Kruskal-Wallis test
1	RMGI	95.74	20.07	49.64	127.5	95.07	H=20.34 P<0.001
	No-Mix	106.09	22.77	66.6	158.7	99.57	
	Sound enamel	112.56	35.15	58.41	164.7	117.10	
7	RMGI	78.84	30.77	18	155.6	78.39	F=8.00 P*<0.001
	No-Mix	79.84	26.89	36.87	144.7	76.13	
	Sound enamel	78.64	34.02	16.43	149.1	76.11	
14	RMGI	46.95	14.23	29.03	79.09	42.20	H=3.85 P=0.278
	No-Mix	44.95	23.18	5.01	110	44.53	
	Sound enamel	50.13	28.13	12.62	121.4	47.10	
28	RMGI	24.48	17.18	0	58.79	24.60	H=7.36 P=0.061
	No-Mix	12.48	12.84	0	50.06	8.80	
	Sound enamel	15.47	17.73	0	57.45	8.73	

*One-way ANOVA and Kruskal-Wallis test

Table 4. Comparison of the amount of released fluoride in the artificial saliva among the groups at each time point

Time (Days)	Group	Mean (PPM)	Std. deviation	Minimum	Maximum	Median	One-way ANOVA
1	RMGI	83.97	15.54	66.60	104.50	84/41	F=46.61 P<0.001
	No-Mix	128.80	30.64	75.51	159.00	139.28	
	Sound enamel	3.64	2.60	0.90	7.53	2.86	
7	RMGI	77.94	35.57	50.70	144.70	63.85	H=14.41 P*=0.002
	No-Mix	90.73	31.07	60.90	149.10	87.16	
	Sound enamel	1.99	2.18	0.00	5.10	1.04	
14	RMGI	44.20	15.31	25.08	61.70	49.20	H=13.39 P*=0.004
	No-Mix	46.49	14.33	19.19	57.50	52.92	
	Sound enamel	1.08	1.73	0.00	4.50	0.45	
28	RMGI	12.09	8.41	0	24.78	12.40	F=6.70 P=0.082
	No-Mix	10.29	13.62	0	34.30	5.75	
	Sound enamel	0.57	1.24	0	3.10	0.05	

*Kruskal-Wallis

Mouthwash Subgroups

According to Table 5, on day 1, the highest and lowest fluoride release occurred in the RMGI and sound enamel groups, respectively. The amount of released fluoride differed significantly between the adhesive groups (P=0.027).

On day 7, the highest and lowest fluoride release occurred in the No-Mix and sound enamel groups, respectively. The amount of released fluoride was not significantly different between the adhesive groups (P=0.279).

On day 14, the highest and the lowest fluoride release occurred in the RMGI and sound enamel groups, respectively. The amount of released fluoride was not significantly different between the adhesive groups (P=0.750).

On day 28, the highest and lowest fluoride release occurred in the RMGI and No-Mix groups, respectively. The difference in the amount of released fluoride was not significant between the adhesive groups (P=0.216).

Pairwise comparisons of the groups on day 1 revealed that the mean amount of released fluoride in the RMGI group was significantly higher than that in the Transbond XT group (P=0.024). No other significant differences were found (P>0.05).

Table 5. Comparison of the amount of released fluoride in the NaF mouthwash among the groups at each time point

Time (Days)	Group	Mean (PPM)	Std. deviation	Minimum	Maximum	Median	One-way ANOVA
1	RMGI	118.26	23.02	97.04	158.70	114.75	F=3.79 P=0.027
	No-Mix	112.79	38.53	72.51	164.70	110.85	
	Sound enamel	92.19	7.07	82.40	102.10	91.96	
7	RMGI	73.41	7.97	65.19	87.01	72.72	F=1.37 P=0.279
	No-Mix	80.67	16.84	59.22	103.70	78.31	
	Sound enamel	57.81	39.39	11.40	125.70	54.35	
14	RMGI	42.84	17.71	24.04	73.10	37.71	F=0.41 P=0.750
	No-Mix	38.97	27.01	12.62	84.34	29.26	
	Sound enamel	32.23	7.79	21.70	42.79	33.11	
28	RMGI	25.39	15.58	6.50	50.06	23.27	H=4.46 P*=0.216
	No-Mix	7.17	15.30	0.00	38.14	0.00	
	Sound enamel	17.26	12.31	0.00	34.97	17.42	

*Kruskal-Wallis

Discussion

This study compared the effects of fluoride-containing compounds on the amount of fluoride released from orthodontic adhesives within 28 days. The results showed that the amount of fluoride released from orthodontic adhesives decreased over time. No-Mix composite resin and RMGI responded differently when exposed to fluoride-containing compounds in the early days. Nonetheless, this difference decreased over time at 14 and 28 days, such that the difference in fluoride release between the different fluoride compounds was no longer significant in the No-Mix and RMGI groups at either time point.

Moreover, the amount of fluoride released by different adhesives did not differ significantly at 14 and 28 days. Also, at 1 and 7 days, the difference in released fluoride was significant only between sound enamel and the other adhesive groups, and the adhesive groups showed no significant differences between themselves. Thus, in the long term, no difference exists between No-Mix composite resin and RMGI in fluoride ion release.

The fluoride-releasing capacity of different restorative materials varies depending on environmental conditions such as the saliva pH (22). Other factors, such as the powder/liquid ratio, the restorative cement structure, and the fluoride release potential after complete setting, affect fluoride release. In the present study, the reduction in fluoride release over time was significant in all adhesives. In previous studies, a similar trend of reduced fluoride ion release was observed, with maximum release on day 1 and a significant decrease thereafter (23–26).

The rapid decline in fluoride release from glass-ionomers over time can be attributed to fluoride-containing glass particles dissolving in polyalkenoic acid during setting reactions, thereby reducing the amount of released fluoride. Also, a high release of fluoride on day 1 may be due to superficial washout, whereas in subsequent days, it is mainly released from the pores and deeper crack lines of the cement. It should be noted that variations in reported values across studies can also be due to differences in sample size, the amount of material used, and the methods used to quantify fluoride ions (27). Tay et al. (28) reported a thinner hydrogel layer of Fuji II LC compared with the silica gel layer of conventional glass ionomer. This layer becomes thicker following water sorption, which may explain a reduction in fluoride release after the first week in Fuji II LC. The primary setting of RMGI is induced by light-activated polymerization and completed by acid-base reactions driven by water sorption (28). The amount of released fluoride that can prevent demineralization and caries development has not been precisely specified, and varies from 0.02 to 0.2 ppm in the literature (29). Accordingly, although the trend of fluoride release was descending in the present study, the amount of released fluoride in all adhesive groups remained above this range, even at 28 days, and thus could prevent caries development.

On the other hand, some authors believe that short exposure of adhesives to fluoride cannot sufficiently recharge them to release fluoride in an amount comparable to the amount initially released.

In the study by Arbabzadeh et al. (30), the restorative material was exposed to fluoride mouthwash for 20 minutes, which is not similar to the clinical setting. They showed that, only 2 days after exposure, fluoride release decreased to a minimum. They added that fluoride uptake by the restorative material occurs at the surface and that increased fluoride release thus does not persist for long after exposure. They also stated that initial exposure of glass-ionomer to fluoride makes it more susceptible to subsequent fluoride uptake because this exposure creates pores in the cement matrix (18,30,31).

Arbabzadeh et al. (30) assessed the effects of fluoridated mouthwash and toothpaste on six different glass-ionomer cements. They showed that toothpaste use for 3 weeks had a greater effect on fluoride release from glass-ionomers than did mouthwash use. This effect increased with increased exposure time. They explained that the reason was the higher fluoride concentration in toothpaste than in mouthwash, and suggested increasing the fluoride concentration in mouthwash. Nonetheless, they warned that it can also cause degradation of the cement matrix and adversely affect its mechanical properties; thus, they called for further investigations in this regard.

Similarly, Mousavinasab and Meyer (27) reported higher fluoride release from glass-ionomers after toothpaste use than after mouthwash use. They attributed this to residual toothpaste layers adhering to the surface pores of glass-ionomers.

Staley et al. (32) reported that toothbrushing significantly increased fluoride release from all three types of adhesives and from sound enamel in their study, and RMGI released significantly higher amounts of fluoride than the other groups.

Fluoride release from glass-ionomer cements depends on several factors, including their internal formulation, solubility, and cement porosity. Bahsi et al. (33) reported the highest fluoride release

from Fuji II LC glass-ionomer and attributed it to its chemical composition and mixed cement form.

A 36-month study of fluoride release reported the highest amount of fluoride released from glass ionomer in the first year. In the second year, however, the difference between glass-ionomer, compomer, and composite resin was not significant (34).

Although the amount of released fluoride from RMGI is similar to that of conventional glass-ionomer in most studies, fluoride release from RMGI is not only affected by the complex fluoride compounds and their interactions, but also by the type and amount of resin used for photochemical polymerization reaction (35). Another study by Nassar et al. (21) showed that exposure of glass-ionomer to fluoride varnish increased fluoride recharge and subsequent fluoride release, findings similar to those of the present study.

In the present study, we used sound enamel instead of composite resin discs for bracket bonding to better simulate the clinical setting, which was a strength of this study. However, prior exposure of the tooth to fluoride before extraction can affect the amount of fluoride released from the enamel. To minimize this effect, all teeth were cleaned with a brush and pumice paste before bracket bonding.

Nevertheless, further long-term clinical studies are required to better clarify the fluoride release and recharge behavior of orthodontic adhesives in the oral environment.

Limitations

Small sample size, inability of the in vitro model to fully simulate oral conditions (including thermal cycling, salivary flow, biofilm accumulation, and the masticatory stresses), and the potential variability introduced by the baseline fluoride exposure of the extracted premolars are among the limitations of this study. Moreover, in the present study, the teeth were evaluated for only 28 days. Future studies with longer assessment periods are required. Further studies on various fluoridated compounds and their effects on the other physical properties of bonding agents over long periods are also recommended.

Conclusion

The present results revealed that the amount of fluoride released from all adhesives decreased over time. However, even the amount of fluoride released after 28 days was capable of preventing white spot lesions. Although fluoride release decreased over time, the measured levels remained within the range reported to contribute to enamel remineralization. Therefore, fluoride-releasing orthodontic adhesives may help reduce the risk of white spot lesions during orthodontic treatment.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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