

Original Article



Comparative Evaluation of Fluoride Release and Rechargeability in Novel Resin-Based and Various Pit and Fissure Sealants: An in Vitro Study

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Abstract

Introduction: Dental caries is a major global health concern, and the occlusal surfaces of molars are particularly vulnerable because of their deep pits and fissures. Sealants effectively prevent caries on these vulnerable surfaces. Researchers have extensively studied fluoride release from various sealant types, but the fluoride release and rechargeability of novel bioactive resin-based sealants remain unexamined. This study investigated the fluoride release and rechargeability of five sealant materials, with a particular focus on novel bioactive resin-based sealants.

Methods: Five dental sealants were evaluated: a non-fluoride-releasing resin-based sealant (Concise™), a fluoride-releasing resin-based sealant (Clinpro™), a bioactive resin-based sealant (BioCoat®), a giomer sealant (BeautiSealant), and a glass ionomer sealant (Fuji VII®). Disk-shaped specimens (11 × 1 mm) were prepared (n = 7 per group) and submerged in 3 mL of deionized water at 37°C. Fluoride release was measured on days 1–7, 14, and 21, using a fluoride ion-selective electrode. After 21 days, the specimens were treated with a 1.23% acidulated phosphate fluoride (APF) gel for 4 minutes, and the fluoride release was evaluated daily for 5 days under the same conditions.

Results: Initial fluoride release was highest for Fuji VII®, followed by BeautiSealant, Clinpro™, BioCoat®, and Concise™. After fluoride recharge, Fuji VII® showed the highest release, followed by BeautiSealant, BioCoat®, Clinpro™, and Concise™ ($P < 0.001$).

Conclusion: The fluoride-releasing and recharging abilities of bioactive resin-based sealants highlighted their potential as a viable dental alternative for pit and fissure protection.

Introduction

Dental caries is a global health concern and ranks among the most prevalent non-communicable diseases affecting people of all ages.¹ A systematic review reported a global incidence of 46.2% in primary teeth and 53.8% in permanent teeth.² When left untreated, dental caries can diminish the quality of life, affecting daily activities such as severe toothache, difficulty chewing, decreased weight, disturbed sleep, and subpar academic performance.³

Dental caries develops through a complex interplay of genetic, physiological, environmental, and behavioral factors.⁴ Studies indicate that teeth are more susceptible to caries within the first few years following the eruption of permanent teeth.⁵ The first permanent molar is especially vulnerable to this occurrence, as it is the first permanent tooth to emerge in the oral cavity. Newly erupted teeth are highly susceptible because their enamel is immature, making them more prone to demineralization due to cariogenic biofilms and inadequate fluoride exposure.⁶ Kashbour et al.⁵ recorded the highest frequency of dental

caries among adolescents and children over the age of six years on the occlusal surfaces of posterior teeth. These teeth have pits and fissures that promote the establishment and retention of caries biofilms,⁵ increasing the risk of tooth decay.¹

Contemporary dental care has transformed from conventional restorative approaches to minimally invasive and preventive strategies. Dentists now focus on maintaining the integrity of natural tooth structure.⁷ One of the most effective interventions for protecting vulnerable tooth surfaces is pit and fissure sealants.^{1,8} Studies indicate that sealants prevent caries formation and inhibit the progression of non-cavitated occlusal lesions, in line with the principles of minimally invasive dentistry.^{1,9}

Dental sealants were initially introduced to protect occlusal surfaces from caries; however, their application has expanded to include managing and controlling early carious lesions on both occlusal and proximal surfaces.⁵ Sealants serve as a physical barrier, which diminishes the

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likelihood of caries by preventing the retention of food debris and microbial plaque on the occlusal surface.^{1,5} The most commonly used sealant materials are resin sealant and glass ionomer sealant, while recent advancements in dental science have identified a broader range of materials with improved properties.¹ A novel bioactive resin-based sealant has recently been introduced to the market. This product uses innovative microcapsule technology that facilitates gradual fluoride release, unlike conventional materials that release fluoride primarily within the first few days. This bioactive resin-based sealant claims to provide a prolonged release of fluoride, along with calcium and phosphate, to enhance remineralization of tooth surfaces.¹⁰

Numerous reports have been published on fluoride release from sealants, but none have examined the fluoride release and rechargeability of bioactive sealants. Therefore, this study analyzed the fluoride release and rechargeability of five sealant materials, focusing particularly on bioactive sealants. The null hypothesis stated that there were no significant differences in fluoride release and rechargeability between the five dental sealant types investigated.

Methods

Sample Size Calculation

The sample size was determined following Asavanund et al.,¹¹ who calculated the mean fluoride concentration measured on day 21 using G*Power software (version 3.1.2) with a one-way ANOVA, setting α to 0.05 and β to 0.10. The analysis indicated a sample size of 35, with 7 samples per group.

Procedural Steps

This in vitro study evaluated five brands of dental sealants: Concise™ White Sealant (3M EPSE, St. Paul, MN), a non-fluoride-releasing resin-based sealant, Clinpro™ (3M EPSE, St. Paul, MN), a fluoride-releasing resin-based sealant, BioCoat® (Premier®, PA, USA), a bioactive resin-based sealant, BeautiSealant (Shofu, San Marcos, USA), a giomer-based sealant, and Fuji VII® (GC Corporation, Tokyo, Japan), a glass ionomer sealant.

For sample preparation, each sealant was placed in a mold with an inserted nylon thread to facilitate suspension and retrieval in deionized water. The mold measured 11 mm in diameter and 1 mm in thickness. After the sealant solidified as instructed by the manufacturer, the sample was immersed in a polyethylene tube containing 3 mL of deionized water, which was replaced daily. Containers were used for each material group ($n=7$), and the samples were kept at 37°C throughout the study period.¹¹

The fluoride concentration in the deionized water of each tube was assessed and documented on days 1, 2, 3, 4, 5, 6, 7, 14, and 21. For each measurement, 0.3 mL of TISAB III (Total Ionic Strength Adjustment Buffer, 940911, Orion Research Inc., Beverly, MA) was added

to the water, stirred for 3 minutes, and analyzed using a fluoride ion-selective electrode (ORION 9409 BN, Thermo Electron Corp., Waltham, MA). The electrode was calibrated before each measurement, and the fluoride concentration was calculated in parts per million (ppm). The values were recorded following triplicate measurements for each sample.¹¹

After the initial 21-day study period, each specimen was rinsed with deionized water, dried with paper, and immersed in 1.23% acidulated phosphate fluoride (APF) gel (12,300 ppm fluoride, pH = 3.5) (Sultan Healthcare Inc., Englewood, NJ) for 4 minutes. Following this treatment, the specimens were rinsed again with deionized water, dried with paper, and placed in fresh deionized water daily. The tubes were stored at 37°C under controlled conditions. Fluoride levels were measured and recorded daily throughout this 5-day period.¹¹

The means and standard deviations for each experimental group were calculated. Data were analyzed using SPSS 26 (IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) was employed to assess fluoride release from the five sealant types on the same day, as well as differences within the same sealant type between consecutive days. Pairwise comparisons were conducted using the least significant difference (LSD) post hoc test, with statistical significance set at $P < 0.05$.

Results

Fluoride release was measured from the five sealant types over the next 21 days and after 5 days of exposure to 1.23% APF gel.

Fluoride Release During the Initial 21-day Period

Table 1 displays the average fluoride release ($\pm$ SD) in ppm from the five tested sealants over 21 days. All the sealants exhibited peak fluoride release on day 1, followed by a significant decrease over time ($P < 0.001$), except for Concise™, which showed no fluoride release during the first 21 days ($P = 0.530$). Fuji VII® demonstrated the highest fluoride release (40.34 ± 3.94 ppm), significantly exceeding BeautiSealant™ (6.22 ± 1.26 ppm), Clinpro™ (1.22 ± 0.31 ppm), Biocoat® (0.10 ± 0.04 ppm), and Concise™ (0.00 ± 0.00 ppm) ($P < 0.001$). Fluoride release from all sealants progressively declined over the 21-day period. By day 4, fluoride release from Biocoat® had dropped to undetectable levels, while Fuji VII® continued to show the highest fluoride release, followed by BeautiSealant™ and Clinpro™ throughout the rest of the study ($P < 0.001$).

Fluoride Release after Exposure to 1.23% APF Gel

Table 2 presents the fluoride release following recharging with 1.23% APF gel. All the fluoride-releasing sealants exhibited a significant increase in fluoride release following recharge ($P < 0.001$), with Fuji VII® exhibiting the highest fluoride release on day 1 post-recharge (39.20 ± 7.85 ppm), followed by BeautiSealant™ (27.86 ± 5.46 ppm), Biocoat® (9.91 ± 7.36 ppm),

Table 1. Mean ($\pm$ standard deviation) concentration in parts per million of fluoride released by each sealant on days 1-7, 14 and 21.

Sealant	Time in days									P-value
	1	2	3	4	5	6	7	14	21	
Concise™	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{AC, a}	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{A, a}	0.00 $\pm$ 0.00 ^{A, a}	0.530
Clinpro™	1.22 $\pm$ 0.31 ^{A, a}	0.34 $\pm$ 0.06 ^{A, b}	0.28 $\pm$ 0.06 ^{A, b}	0.22 $\pm$ 0.03 ^{AC, b}	0.19 $\pm$ 0.01 ^{AC, b}	0.16 $\pm$ 0.07 ^{A, b}	0.16 $\pm$ 0.09 ^{A, b}	0.11 $\pm$ 0.06 ^{A, b}	0.08 $\pm$ 0.06 ^{A, b}	<0.001
Biocoat®	0.10 $\pm$ 0.04 ^{A, a}	0.03 $\pm$ 0.00 ^{A, b}	0.02 $\pm$ 0.01 ^{A, b}	0.00 $\pm$ 0.00 ^{A, c}	0.00 $\pm$ 0.00 ^{A, c}	0.00 $\pm$ 0.00 ^{A, c}	0.00 $\pm$ 0.00 ^{A, c}	0.00 $\pm$ 0.00 ^{A, c}	0.00 $\pm$ 0.00 ^{A, c}	<0.001
Fuji VII®	40.34 $\pm$ 3.94 ^{B, a}	21.97 $\pm$ 4.55 ^{B, b}	16.18 $\pm$ 3.93 ^{B, c}	12.60 $\pm$ 2.58 ^{B, d}	10.46 $\pm$ 1.92 ^{B, d}	9.11 $\pm$ 1.99 ^{B, d}	8.62 $\pm$ 1.88 ^{B, d}	6.23 $\pm$ 1.96 ^{B, d}	3.97 $\pm$ 1.41 ^{B, d}	<0.001
BeautiSealant	6.22 $\pm$ 1.26 ^{C, a}	2.13 $\pm$ 0.89 ^{A, b}	1.59 $\pm$ 0.62 ^{A, b}	1.36 $\pm$ 0.53 ^{C, b}	1.13 $\pm$ 0.58 ^{C, b}	0.95 $\pm$ 0.30 ^{A, b}	0.80 $\pm$ 0.34 ^{A, b}	0.52 $\pm$ 0.24 ^{A, b}	0.35 $\pm$ 0.19 ^{A, b}	<0.001
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	

Statistically significant at P -value < 0.05 determined by one-way ANOVA. Different uppercase letters indicate statistical significance in a column (comparing between sealants). Different lowercase letters indicate statistical significance in a row (comparing between days).

Table 2. Mean ($\pm$ standard deviation) concentration in parts per million of fluoride released by each sealant 5 days after exposure to 1.23% acidulated phosphate fluoride gel.

Sealant	Time in days						
	Before exposure to APF gel			After exposure to APF gel			
	21	1 / 22	2 / 23	3 / 24	4 / 25	5 / 26	P-value
Concise™	0.00±0.00 ^{A, a}	0.00±0.00 ^{A, a}	0.02±0.05 ^{A, a}	0.01±0.04 ^{A, a}	0.00±0.00 ^{A, a}	0.00±0.00 ^{A, a}	0.558
Clinpro™	0.08±0.06 ^{A, a}	1.29±0.61 ^{A, b}	0.26±0.07 ^{A, c}	0.20±0.04 ^{AC, c}	0.16±0.02 ^{A, c}	0.15±0.02 ^{A, c}	<0.001
Biocoat®	0.00±0.00 ^{A, a}	9.91±7.36 ^{B, b}	0.54±0.53 ^{A, c}	0.18±0.14 ^{AC, c}	0.09±0.03 ^{A, c}	0.05±0.02 ^{A, c}	<0.001
Fuji VII®	3.97±1.41 ^{B, a}	39.20±7.85 ^{C, b}	13.07±2.42 ^{B, c}	9.49±2.00 ^{B, c}	8.19±1.91 ^{B, c}	7.26±1.67 ^{B, c}	<0.001
BeautiSealant	0.35±0.19 ^{A, a}	27.86±5.46 ^{D, b}	2.43±1.07 ^{C, c}	1.13±0.45 ^{C, c}	0.70±0.23 ^{A, c}	0.54±0.15 ^{A, c}	<0.001
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	

Statistically significant at P -value < 0.05 determined by one-way ANOVA. Different uppercase letters indicate statistical significance in a column (comparing between sealants). Different lowercase letters indicate statistical significance in a row (comparing between days).

Clinpro™ (1.29 ± 0.61 ppm), and Concise™ (0.00 ± 0.00 ppm). A statistically significant difference was observed ($P < 0.001$). Over the following days, fluoride release from all materials decreased rapidly. By day 5, Fuji VII® (7.26 ± 1.67) exhibited significantly higher fluoride release than all the other sealants ($P < 0.001$). By contrast, BeautiSealant™ (0.54 ± 0.15), Biocoat® (0.05 ± 0.02), Clinpro™ (0.15 ± 0.02), and Concise™ (0.00 ± 0.00) showed minimal or undetectable release, with no statistically significant differences between these four sealants.

Discussion

This study investigated the fluoride release and rechargeability of five sealant types, including a non-fluoride-releasing resin-based sealant, a fluoride-releasing resin-based sealant, a bioactive resin-based sealant, a giomer-based sealant, and a glass ionomer sealant. The results showed significant differences in fluoride release between the tested sealants during the initial 21-day period and after treatment with 1.23% APF gel.

Fluoride release from sealants was influenced by material composition, powder-to-liquid ratio, mixing technique, solubility, porosity, surface area exposure, and environmental pH.^{12,13} Fluoride recharge and re-release depend on material composition, frequency of fluoride exposure, and the formulation and concentration levels of fluoridating agents. Higher porosity allows greater fluoride uptake and storage, increasing re-release. These factors contribute to differences in fluoride release and rechargeability between sealant materials.¹⁴

On the first day, Fuji VII® showed the highest fluoride release, followed by BeautiSealant, Clinpro™, and BioCoat®, while Concise™ showed no fluoride release. After this initial phase, fluoride release decreased over time until it reached a plateau. Although the fluoride release values of Concise™, Clinpro™ and BioCoat® differed numerically, no significant differences were observed between these three sealants at any evaluated time point. Clinpro™ showed a numerically higher initial value than BioCoat®, but both materials exhibited a similar time-dependent decline, whereas fluoride release from Concise™ remained negligible throughout the observation period. Fuji VII® released significantly more fluoride than all three sealants at every time point evaluated. In contrast, the statistical significance of the differences between BeautiSealant and these three sealants varied over time. Fuji VII® also released significantly more fluoride than BeautiSealant throughout the observation period. These findings concurred with previous studies that reported similar patterns of fluoride release.^{11–13,15–17}

A *burst effect* was observed in Fuji VII®, a glass ionomer sealant, and BeautiSealant, a giomer-based sealant comprising pre-reacted glass ionomer (PRG) fillers within a resin-based monomer matrix, characterized by a pronounced surge in fluoride release within the

first 24 hours. This rapid initial release resulted from the dissolution of glass particles in polyalkenoate acid during the setting reaction. This burst effect may also be linked to the initial superficial rinsing, while the ongoing release of fluoride in subsequent days was attributed to fluoride's ability to diffuse through the pores and fractures of the cement.^{12,17} The burst effect reported in BeautiSealant was inferior to Fuji VII®, consistent with previous research indicating a reduced burst effect in giomer compared to glass ionomer.^{12,13,16} The Clinpro™ and BioCoat® fluoride-releasing resin-based sealants released minimal fluoride. This finding aligned with other studies reporting that resin-based sealants release less fluoride than sealants containing glass particles because fluoride release from resin-based sealants is directly proportional to the material's fluoride content.^{11–13,18}

Although the tested sealants showed substantial differences in fluoride release, even low fluoride concentrations may influence the demineralization–remineralization balance of enamel. Sub-ppm fluoride levels have been shown to reduce enamel demineralization and promote mineral deposition, with concentrations of 0.01–0.2 ppm reported to stimulate hydroxyapatite crystal growth, thereby supporting remineralization.¹⁹ Thus, the relatively low fluoride levels released by some of the tested sealants may still be biologically relevant, although higher and more sustained fluoride release may provide greater fluoride availability. However, the concentrations measured in this study cannot be directly extrapolated to the oral environment, where salivary flow, fluoride clearance, pH fluctuations, and other ions may influence fluoride availability and its effects on enamel.

After recharging with 1.23% APF, all sealants except Concise™ released markedly higher levels of fluoride than the preceding day. Fluoride ion concentration increased during the initial 24 hours and then declined rapidly to levels recorded before APF gel exposure within a few days. This increase in fluoride, followed by a decrease, aligned with previous research.^{11,12,16,18,20} The exact mechanism of fluoride recharging remains ambiguous. However, investigations by Xu and Burgess²¹ in 2003, along with numerous subsequent studies, suggested that materials which initially emit higher quantities of fluoride exhibit enhanced recharging potential.^{11,12,16,18,20}

After recharging with 1.23% APF, some fluoride was released from Concise™, possibly because the acidic APF gel altered the sealant surface and facilitated temporary fluoride uptake and release, despite its non-fluoride-releasing formulation.²² This result aligned with Bayrak et al,²⁰ who also found that composite resins release some fluoride after being recharged with APF gel, probably associated with surface-retained fluoride. However, the negligible amount detected is unlikely to be clinically relevant and may primarily reflect transient surface fluoride retention rather than functional fluoride-releasing activity.

BioCoat® is a bioactive resin-based sealant developed to release fluoride and other ions. Our results indicated that the initial fluoride release by BioCoat® was inferior to Fuji VII®, BeautiSealant, and Clinpro™. Release peaked on the first day and then declined significantly. By day 4, the fluoride concentration produced by BioCoat® was undetectable, similar to Concise™. Bioactive sealants like BioCoat® are believed to release fluoride through microcapsule-based SmartCap™ Technology. These microcapsules consist of a polyurethane semi-permeable membrane that contains ionic solutions of fluoride, calcium, and phosphate designed to diffuse through the sealant into adjacent tooth structures by adhering to the concentration gradient. This also allows the ingress of aqueous solutions containing similar ions to replenish the sealant.¹⁰

Interestingly, after recharging with 1.23% APF gel, BioCoat® released significantly more fluoride than Clinpro™ on the first day after recharging. However, the differences markedly decreased by the second day, and no statistically significant difference was observed between the two resin-based sealants thereafter. The initial surge in fluoride release from BioCoat® after recharging may be attributed to its SmartCap™ microcapsules. The semi-permeable membrane of these microcapsules allows fluoride-containing solutions to enter and replenish their ionic content, as described in the manufacturer's technical information.¹⁰ Therefore, exposure to APF gel may have resulted in fluoride uptake into the microcapsules, followed by rapid re-release during the first 24 hours. The low pH of the APF gel may also have contributed to this transient increase by influencing fluoride uptake and release at the material surface. However, whether the acidic environment alters polyurethane microcapsule permeability remains unclear. Further studies are needed to clarify the specific mechanism responsible for the pronounced but temporary increase in fluoride release after APF gel exposure.

This study rejected the null hypothesis, confirming the significant differences in fluoride release and recharge abilities among the five sealant types. This in vitro study was conducted under controlled conditions, but the findings may not fully represent material behavior in the oral environment. Further in vitro and in vivo studies are warranted to validate our findings and determine their clinical relevance.

Conclusion

This study demonstrated that the glass ionomer sealant exhibited the highest fluoride release and rechargeability, followed by the giomer-based sealant. The resin-based sealants showed lower fluoride release overall, with different release patterns observed before and after fluoride recharge. Our findings suggest that while glass ionomer sealants remain the most effective in fluoride release and rechargeability, bioactive resin-based sealants

offer a promising alternative for pit and fissure sealing due to their fluoride-releasing and recharging properties.

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Authors' Contribution

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Competing Interests

The authors declare no competing interests.

Ethical Approval

Not applicable. This in vitro study did not involve human participants, identifiable human data, extracted teeth, or any biological specimens of human origin. Therefore, ethical approval was not required according to our institutional and national research guidelines.

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References

1. Ng TC, Chu CH, Yu OY. A concise review of dental sealants in caries management. *Front Oral Health* 2023;4:1180405. doi:10.3389/froh.2023.1180405
2. Kazeminia M, Abdi A, Shohaimi S, Jalali R, Vaisi-Raygani A, Salari N, et al. Dental caries in primary and permanent teeth in children's worldwide, 1995 to 2019: a systematic review and meta-analysis. *Head Face Med* 2020;16(1):22. doi:10.1186/s13005-020-00237-z
3. Alanzi A, Husain F, Husain H, Hanif A, Baskaradoss JK. Does the severity of untreated dental caries of preschool children influence the oral health-related quality of life? *BMC Oral Health* 2023;23(1):552. doi:10.1186/s12903-023-03274-7
4. Cogulu D, Saglam C. Genetic aspects of dental caries. *Front Dent Med* 2022;3:1060177. doi:10.3389/fdmed.2022.1060177
5. Kashbour W, Gupta P, Worthington HV, Boyers D. Pit and fissure sealants versus fluoride varnishes for preventing dental decay in the permanent teeth of children and adolescents. *Cochrane Database Syst Rev* 2020;11(11): CD003067. doi:10.1002/14651858.CD003067.pub5
6. Lynch RJ. The primary and mixed dentition, post-eruptive enamel maturation and dental caries: a review. *Int Dent J* 2013;63(Suppl 2):3-13. doi:10.1111/idj.12076
7. Alyahya Y. A narrative review of minimally invasive techniques in restorative dentistry. *Saudi Dent J* 2024;36(2):228-33. doi:10.1016/j.sdentj.2023.11.005
8. Desai H, Stewart CA, Finer Y. Minimally invasive therapies for the management of dental caries-a literature review. *Dent J (Basel)* 2021;9(12):147. doi:10.3390/dj9120147

9. Wright JT, Crall JJ, Fontana M, Gillette EJ, Nový BB, Dhar V, et al. Evidence-based clinical practice guideline for the use of pit-and-fissure sealants: a report of the American Dental Association and the American Academy of Pediatric Dentistry. *J Am Dent Assoc* 2016;147(8):672-82.e12. doi:10.1016/j.adaj.2016.06.001
10. Premier Dental Products Company. BioCoat™ Part 2: Pit-And-Fissure Sealant Incorporating SmartCap™ Technology [Internet]. Plymouth Meeting, PA: Premier Dental Products Company; 2017. Available from: https://www.premierdentalco.com/wp-content/uploads/2017/04/biocoat_technical-guide_PART2_R1.pdf. Accessed July 4, 2025.
11. Asvanund Y, Rirattanapong P, Akulchakit W. Fluoride release and recharge ability of glass-ionomer and fluoride releasing resin-based tooth sealant. *Southeast Asian J Trop Med Public Health* 2021;52(1):70-6.
12. Patil SS, Kontham UR, Kontham RK, Patil SS, Kamble SP. Fluoride release and fluoride-recharging ability of three different sealants. *J Indian Soc Pedod Prev Dent* 2020;38(3):247-52. doi:10.4103/jisppd.Jisppd_345_19
13. Şişmanoğlu S. Fluoride release of giomer and resin-based fissure sealants. *Odovtos Int J Dent Sci* 2019;21(2):45-52. doi:10.15517/ijds.v0i0.36860
14. Kumari PD, Khijmatgar S, Chowdhury A, Lynch E, Chowdhury CR. Factors influencing fluoride release in atraumatic restorative treatment (ART) materials: a review. *J Oral Biol Craniofac Res* 2019;9(4):315-20. doi:10.1016/j.jobcr.2019.06.015
15. Klaophimai A, Komalsingsakul A, Srisatjaluk RL, Senawongse P. Benefits of pit and fissure sealants on fluoride release, buffering capacity, and biofilm formation. *M Dent J* 2021;41(2):179-86.
16. Senthilkumar A, Chhabra C, Trehan M, Pradhan S, Yadav S, Shamsudeen NH. Comparative evaluation of fluoride release from glass ionomer, compomer, and giomer sealants following exposure to fluoride toothpaste and fluoride varnish: an in vitro study. *Int J Clin Pediatr Dent* 2022;15(6):736-8. doi:10.5005/jp-journals-10005-2477
17. Singh H, Rashmi S, Pai S, Kini S. Comparative evaluation of fluoride release from two different glass ionomer cement and a novel alkasite restorative material-an in vitro study. *Pesqui Bras Odontopediatria Clin Integr* 2020;20: e5209. doi:10.1590/pboci.2020.019
18. Bansal R, Bansal T. A comparative evaluation of the amount of fluoride release and re-release after recharging from aesthetic restorative materials: an in vitro study. *J Clin Diagn Res* 2015;9(8): ZC11-4. doi:10.7860/jcdr/2015/11926.6278
19. Lynch RJ, Navada R, Walia R. Low-levels of fluoride in plaque and saliva and their effects on the demineralisation and remineralisation of enamel; role of fluoride toothpastes. *Int Dent J* 2004;54(5 Suppl 1):304-9. doi:10.1111/j.1875-595x.2004.tb00003.x
20. Bayrak S, Tunc ES, Aksoy A, Ertas E, Guvenc D, Ozer S. Fluoride release and recharge from different materials used as fissure sealants. *Eur J Dent* 2010;4(3):245-50. doi:10.1055/s-0039-1697835
21. Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. *Biomaterials* 2003;24(14):2451-61. doi:10.1016/s0142-9612(02)00638-5
22. Gavini S, Devalla S, Shankarappa P, Padmaja M, Tiriveedi R, Ramakrishna J. Effect of fluoride recharge on the microleakage of fluoride-releasing restorative materials: an ex vivo confocal laser scanning microscopy study. *J Int Soc Prev Community Dent* 2022;12(2):216-25. doi:10.4103/jispcd.JISPCD_283_21