FLUORIDE

Quarterly reports

EVALUATION OF THE EFFECTS OF FLUORIDE RELEASE BY DIFFERENT RESTORATIVE MATERIALS

Unique digital address (Digital object identifier [DOI] equivalent):
https://www.fluorideresearch.online/epub/files/234.pdf

Mustafa Oktay[1], Mine Koruyucu[1]

[1]Istanbul University, Faculty of Dentistry, Department of Pedodontics, Istanbul, Turkey.

***Corresponding author:**
Mustafa Oktay, Istanbul University, Faculty of Dentistry, Department of Pedodontics, Istanbul, Turkey.
Email: mustafaoktay@istanbul.edu.tr
Phone: +(90)545 321 48 31
Accepted: 2023 Dec 5
Published:2023 Dec 5

ABSTRACT

Dental caries is one of the common preventable diseases. And it is amongst the primary causes of oral pain and tooth loss. Fluoride is reported as an effective and safe agent in the prevention and control of dental caries. Therefore, today many products such as gel, varnish, toothpaste, and restorative materials contain fluoride ions, and restorative materials that can release fluoride are preferred in dental treatments. Today, there are many fluoride-containing restorative materials, including glass ionomer cements, compomers, glass carbomers, giomers, and fluoride-containing composite resins. When the studies are examined, there are many studies on the fluoride release of the restorative materials that release fluoride on the discs, and there are a limited number of studies on the ion releases other than fluoride on the teeth. Therefore, in this study, it was aimed to investigate the ion release of various restorative materials that release fluoride to primary teeth in vitro. In the study, Ionofil U (cgic), Dyract XP (compomer), EQUIA Fil (glass hybrid), SDR plus U (composite) and Beautifil-Bulk (giomer) materials were used. The ion release concentrations of the materials in the primary teeth on the 1st, 14th and 35th days were evaluated in the SEM device in the EDAX TEAM program. As a result of this research, amongst the restorative materials used, the highest average fluoride release value was determined in the glass ionomer group, followed by glass hybrid restorative material, compomer, giomer and bulk flow composite material, and in line with these findings, higher fluoride release and the decrease in fluoride release over time were found to be other. It has been predicted that glass ionomer cements and glass hybrid restorative materials may be appropriate, especially in patients with high caries risk, because they are less than other materials

Key-words: Ion release; Primary teeth; Restorative Materials.

INTRODUCTION

Dental caries is one of the common preventable diseases, and societies have always been sensitive to this disease throughout their lives[1]. Dental caries is among the primary causes of oral pain and tooth loss[2]. This disease develops over time through a complex interaction between acid-producing bacteria, fermentable carbohydrates, and many host factors, including teeth and saliva. It can manifest as an aggressive condition that affects both the crowns and roots of teeth, particularly in early childhood, impacting primary teeth[3]. Fluoride has been reported to be an effective and safe agent in the prevention and control of dental caries. Therefore, many products today, such as gels, varnishes, toothpaste, and restorative materials, contain fluoride ions. Restorative materials capable of fluoride release are preferred in dental treatments[4]. Currently, there are various fluoride-containing restorative materials available, including glass ionomer cements, compomers, glass carbomers, giomers, and fluoride-containing composite resins[5]. Mechanical properties and fluoride-releasing capabilities vary among different materials. Compomers, glass ionomers, and resin-modified glass ionomers generally have weaker properties compared to composite resins. Therefore, the clinical applications of fluoride-releasing materials are often limited to relatively small-sized restorations in moderately loaded areas[6]. The anticariogenic effect of fluoride-releasing materials depends on the amount and sustainability of fluoride release. The fluoride release from a restorative material is determined by the matrix of the restorative material, the mechanism of its hardening, and the amount of fluoride-containing filler materials. The matrix of resin composites is much less hydrophilic, and the fluoride incorporated into resin composites is released only in small amounts. The fluoride release pattern is typically characterized by an initial rapid release, followed by a significant decrease in the release rate after immersion in water for a few days[7]. When the studies conducted are examined, there can be found numerous studies on the fluoride release of restorative materials on disks; however, limited research exists on fluoride and residual ion release on teeth. Therefore, the aim of this study is to evaluate the ion release of various fluoride-releasing restorative materials on deciduous teeth in vitro.

MATERIAL AND METHODS

The study titled "Evaluation of the Effects of Fluoride-Releasing Different Restorative Materials on Deciduous Teeth In Vitro" was reviewed and deemed ethically appropriate by the Istanbul University Faculty of Dentistry Clinical Research Ethics Committee in the meeting held on May 17, 2022, under file number 2022/25, with decision number 124.

As researchers participating in the study titled "Evaluation of the Effects of Fluoride-Releasing Different Restorative Materials on Deciduous Teeth In Vitro," we declare and pledge that we have read the latest version of the World Medical Association's Helsinki Declaration and the Good Clinical Practice Guide/Good Laboratory Practice Guide recently published by the Ministry of Health. We assure that the study will be conducted in accordance with the Helsinki Declaration and Good Clinical Practice/Good Laboratory Practice, and we take full legal and financial responsibility for the study. We also declare that all participating units and personnel have been informed regarding the study.

The caries-free deciduous premolars used in the research were obtained from individuals who had reached the age of physiological resorption and had indications for extraction due to periodontal or orthodontic reasons. The participants agreed to take part in the research regardless of gender.

Cavity preparation in the teeth was completed by a single investigator on the same day. Class I cavities measuring 5 mm x 3 mm x 2 mm were prepared using diamond round burs (012) in the teeth used for evaluating ion release. The materials used in the study were Ionofil U (CGIC), Dyract XP (COMPOMER), EQUIA Fil (HYBRID GLASS), SDR plus U (COMPOSITE), and Beautifil-Bulk (GIOMER). After the samples were prepared, they were stored in an incubator at 37°C for 24 hours. In order to better simulate the intraoral environment, finishing was performed using a 12-blade tungsten carbide bur with an aerator in all groups. Subsequently, the samples were polished using aluminum oxide-coated Sof-Lex discs. A total of 125 caries-free primary molars were embedded in acrylic blocks with exposed occlusal surfaces and sectioned longitudinally in a vertical direction using a low-speed diamond separation disc (4 x .012 x ½ METKOM) under water cooling with the Isomet® 1000 device (Buehler, Lake Bluff, IL, USA).

For the evaluation of ion release, all samples were assessed for the ions released into the primary tooth using Energy-Dispersive X-ray Spectroscopy (EDS) under a Scanning Electron Microscope (SEM) on days 1, 14, and 35. Random selections were made to identify points containing ions in each group, and the point with the highest release for each ion was determined. Images were captured at 500X, 1000X, and 2000X magnification using the EDAX TEAM program. EDS analysis determined the values of ions such as sodium, potassium, fluoride, titanium, strontium, barium, zirconium, and aluminum released in each sample.

Statistical Analysis: The data were analyzed using IBM SPSS V23. Normality of the data was examined using the Shapiro-Wilk test. For comparing normally distributed ion release values within groups over time, repeated measures analysis of variance (ANOVA) was used, and multiple comparisons were examined using the Bonferroni test. The Kruskal-Wallis test was used for comparing non-normally distributed data among groups. The analysis results were presented as mean ± standard deviation or median (minimum - maximum) for quantitative data. The significance level was set at $p < 0.050$.

RESULTS

The average values of released fluoride ions over time in teeth restored with Ionofil U (CGIC), Beautifil Bulk (GIOMER), Dyract XP (COMPOMER), SDR Plus U (COMPOSITE), and EQUIA Fill (HYBRID GLASS) show statistically significant differences (p<0.001). The values on day 1, day 14, and day 35 for each restorative material indicate table 1 variations. On day 35, the lowest average values were observed for all materials. (Table 1)

Table 1 Comparison of fluoride values according to time within groups

	1st day	14th day	35th day	p*
IONOFIL U (CGIC)	25,07±2,64[a]	14,73±1,45[b]	3,59±0,49[c]	**<0,001**
BEAUTIFIL BULK (GIOMER)	17,41±2,08[a]	10,14±0,88[b]	1,25±0,19[c]	**<0,001**
DYRACT XP (COMPOMER)	18,94±1,72[a]	9,95±1,14[b]	2,47±0,18[c]	**<0,001**
SDR PLUS U (COMPOSITE)	15,49±1,92[a]	8,29±0,26[b]	0,19±0,05[c]	**<0,001**
EQUIA FILL (HYBRID GLASS)	21,21±2,88[a]	13,57±0,76[b]	4,56±0,35[c]	**<0,001**

*Repeated analysis of variance, mean±s. deviation, a-c: There is no difference between tenses with the same letter.

Statistically significant differences were found in the released fluoride ions among groups on days 1 (p<0.001), 14 (p<0.001), and 35 (p<0.001). The average values for each restorative material at these time points are detailed in Table 2. Notably, on day 35, teeth restored with Ionofil U (CGIC) and EQUIA Fill (HYBRID GLASS) did not show a statistical difference, while other groups exhibited significant variations. Regarding released calcium ions, no statistically significant differences were observed among the groups on days 1 (p=0.259), 14 (p=0.219), and 35 (p=0.673). The specific values for each material on these days are provided in Table 2.

Table 2 Comparison of fluoride and calcium values between groups

	IONOFIL U (CGIC)	BEAUTIFIL BULK (GIOMER)	DYRACT XP (COMPOMER)	SDR PLUS U (COMPOSITE)	EQUIA FILL (HYBRID GLASS)	p
Fluoride 1st day	25,07±2,64[c]	17,41±2,08[ab]	18,94±1,72[ab]	15,49±1,92[a]	21,21±2,88[bc]	**<0,001***
Fluoride 14th day	14,73±1,45[a]	10,14±0,88[b]	9,95±1,14[b]	8,29±0,26[b]	13,57±0,76[a]	**<0,001***
Fluoride 35th day	3,59±0,49[a]	1,25±0,19[b]	2,47±0,18[c]	0,19±0,05[d]	4,56±0,35[a]	**<0,001***
Calcium 1st day	0,22±0,20	0,09±0,04	0,24±0,08	0,17±0,07	0,18±0,05	0,259*
Calcium 14th day	0,07 (0,04 - 0,14)	0,12 (0,07 - 0,23)	0,06 (0,04 - 0,23)	0,14 (0,07 - 0,23)	0,05 (0,03 - 0,13)	0,219**
Calcium 35th day	0,04 (0,03 - 0,13)	0,03 (0,02 - 0,13)	0,04 (0,03 - 0,13)	0,09 (0,01 - 0,23)	0,02 (0,01 - 0,13)	0,673**

*One-way analysis of variance, **Kruskal Wallis test, mean±s. deviation, median (minimum - maximum), a-d: There is no difference between times with the same letter.

There is no statistical difference in the percentage change between Ionofil U (CGIC) and Dyract XP (COMPOMER) for fluoride ions, while differences exist among the other groups. The SDR Plus U (COMPOSITE) group shows the highest percentage change for fluoride ions, while the EQUIA Fill (HYBRID GLASS) group exhibits the lowest. For calcium ions, specific percentage change values are provided for each material on Table 3.

Table 3: Comparison of fluoride and calcium percentage change values according to groups.

	IONOFIL U (CGIC)	BEAUTIFIL BULK (GIOMER)	DYRACT XP (COMPOMER)	SDR PLUS U (COMPOSITE)	EQUIA FILL (HYBRID GLASS)	p
Fluoride exchange percentage	85,70±0,85[b]	92,83±0,37[c]	86,96±0,55[b]	98,80±0,21[d]	78,35±1,33[a]	**<0,001***
Calcium exchange percentage	75,00 (-100,00 - 77,78)	30,00 (0,00 - 70,00)	79,33 (60,61 - 83,33)	18,18 (13,04 - 93,33)	84,62 (50,00 - 93,75)	0,105**

*One-way analysis of variance, **Kruskal Wallis test, mean±s. deviation, median (minimum - maximum), a-d: There is no difference between times with the same letter.

DISCUSSION

Both calcium and fluoride ions have a positive effect on the remineralization and strengthening of tooth tissue. Fluoride also acts as a biocide against Streptococcus mutans in the oral environment. The positive effect of a restoration material that can release ions such as calcium and fluoride is achieved not by increasing the concentration of these ions in saliva, but by releasing ions to the adjacent tooth tissue. In other words, for maximum effectiveness, ions need to be present on the tooth surface, which is susceptible to decay. A restorative material that can release both fluoride and calcium ions is expected to enhance the formation of decay-resistant fluorapatite on the tooth surface. It has been shown that this contributes significantly to preventing tooth decay[8].

Secondary caries formation is one of the common problems encountered in pediatric dentistry. This problem is one of the most important factors affecting the clinical longevity of restorations. It has been observed that the frequency of secondary caries is reduced in restorations made with glass ionomer cements, and the development of various restorative materials containing fluoride has been increased[9]. Currently, there are many fluoride-containing materials available in pediatric dentistry, such as traditional glass ionomers, glass ionomer-based hybrid materials, glass carbomers, giomers, fluoride-added composite resins, and fissure sealants. When reviewing the literature related to ion release from restorative materials, it has been found that the majority of studies focus on glass ionomer-based restorative materials and specifically examine the release of fluoride ions[10-12]. Therefore, the aim of this study is to comparatively evaluate the ion release capacities of different commonly used restorative materials.

There are several factors that affect fluoride release from restorative materials. These factors include material composition and filler content, powder-liquid ratio, type and duration of setting reaction, mixing time and method, chemical form of fluoride in the material, surface energy and porosity of the material, storage conditions, pH of the environment, finishing procedures, and surface area of the material[13]. The number of ions released from restorative materials can be measured both in vivo and in vitro. However, the composition of saliva, pH value, plaque, and pellicle formation in vivo can affect the results of ion measurements. In this study, it was decided to evaluate the ion release of restorative materials under in vitro conditions to achieve easier standardization. In order to make accurate comparisons between groups in in vitro studies, all prepared samples should be of the same standardized dimensions. When examining the dimensions of samples prepared in studies evaluating fluoride release from restorative materials, it was found that cavities of different diameters and heights were prepared in each study[14]. Additionally, it was determined that there is no ISO standard specifically addressing this issue. In this study, all sample groups were kept at 37°C and 100% humidity throughout the research. In in vitro studies involving fluoride ion release published to date, samples have been stored in different environments such as distilled water, deionized water, or artificial saliva. It is reported that deionized water, which does not contain any ions, provides more accurate results for the released ions from the samples. Deionized water has been used in most of the conducted studies. Therefore, in this study, the samples were also stored in deionized water during the experimental period[15-17].

To determine the ion release from materials in vitro studies, spectrophotometric methods, gas and liquid ion chromatography methods, aluminum monofluoride absorption spectrometry, secondary ion mass spectrometry, proton-induced X-ray emission, electron probe microanalysis, X-ray photoelectron spectroscopy, F-ion selective electrode method, and SEM + EDS elemental analysis methods are used. Among these methods, the ion-selective electrode method is frequently preferred. However, for the determination of ion release from restorative materials applied on extracted teeth, EDS elemental analysis method is preferred[18]. In this study, conducted under in vitro conditions, the evaluation of ion release was carried out using the SEM + EDS elemental analysis method.

The source of fluoride in giomer is surface-reacted glass ionomer (PRG). Giomer contains a small amount or no glass ionomer matrix phase. Therefore, significant acid-base reactions are not observed. PRG is pre-reacted with acid, so acid-base reaction in giomer is not significant. Another possible explanation for the difference in fluoride release rate between giomer and glass ionomer is the presence of porosity, which can have a significant effect. The porosity in giomer is less than that in glass ionomer, resulting in less fluoride release. Giomer also contains resin materials that release fluoride and act as barriers against water, and it has a variable solubility as a filling material. Many studies have been conducted on fluoride release from different restorative materials, and various results have been obtained. One of the advantages that make CIS popular as a restorative material is their ability to release fluoride and their antibacterial properties due to low pH during freezing[19].

In a study conducted by Atiyeh Feiz et al. in 2022, fluoride release among different restorative materials was compared. On days 1-7, zirconomer had the highest fluoride release, followed by Cention N (composite), Fuji II LC (RMGIC), and Beautifil (giomer). The lowest fluoride release was observed in Beautifil restorative material on day 21. According to the results of this study, the maximum average fluoride release on days 1, 3, and 7 belonged to the Zirconomer group, and the minimum belonged to the Giomer group. The fluoride release from Zirconomer showed a significant decrease during the measurement period and was approximately equal to the fluoride release from Cention N and resin-modified glass ionomer on day 14.

Throughout the measurement period, giomer was reported to have a nearly constant and minimal fluoride release. Although laboratory studies are recommended to investigate information related to ion release, the true performance of restorative materials can only be determined through long-term clinical studies. Therefore, it is recommended to conduct more clinical research studies with more parameters to evaluate these properties under in vivo environmental conditions[20]. In this study, similar results were obtained within the first 24 hours. The highest fluoride release was observed on the first day in the Ionofil U (CGIC) group. On the 35th day, Equa fill (HYBRID GLASS) was found to be the restorative material with the maximum fluoride release.

Nigam et al. reported in a study that glass ionomer cement had the highest fluoride release among various dental materials within the first 24 hours, with a value of 57.97 ppm. The same study mentioned a significant decrease in fluoride release after the first day. After 24 hours, the material with the highest fluoride release was glass ionomer cement (Ionofil Molar), followed by Fuji IX Extra[21]. Similar results were obtained in this study within the first 24 hours. The highest fluoride release was observed in the Ionofil U (CGIC) group on day 1. On day 35, the restorative material with the maximum fluoride release was Equia Fill (HYBRID GLASS).

In a study by Bayrak et al., the fluoride ion release from giomer (Beautifil II), glass carbomer (GCP Glass-Fill), ceramic-based traditional glass ionomer cement (Amalgomer), polyacid-modified composite resin (Dyract XP), and traditional glass ionomer cement (Fuji

IX Capsule) was investigated. The study reported that the fluoride ion release from resin-based materials was significantly lower compared to glass ionomer-containing restorative materials. Additionally, it was reported that glass carbomer had the highest level of fluoride ion release among the evaluated restorative materials[22]. In this study, there was a statistically significant difference in the percentage change in fluoride ion release among the groups. There was no difference in the percentage change between ionofil U (CGIC) and dyract xp (COMPOMER), while there was a difference among the other groups. The highest change occurred in the SDR plus U (COMPOSITE) group, while the lowest change occurred in the EQUIA fill (HYBRID GLASS) group.

Fluoride-releasing restorative dental materials suppress the formation of caries, reduce, or prevent demineralization, and support the remineralization of tooth hard tissues. While resin composites have satisfactory physical properties, they may lack fluoride-releasing ability and have limited capacity to prevent secondary caries and promote remineralization. Therefore, new restorative materials with protective properties are being developed to overcome the challenges associated with traditional glass ionomers and composite resins. Hybrid materials have been developed that maintain their clinical benefits while addressing the difficulties associated with traditional glass ionomers and composite resins[23]. Among these hybrid materials, Activa, a bioactive restorative material, contains bioactive glass and is reported to be more bioactive than traditional glass ionomers, releasing Ca, P, and F ions while increasing pH. Equia Forte Fill, a type of high-viscosity glass ionomer cement (HVGIC), is less sensitive to moisture, has better wear resistance and hardness compared to traditional glass ionomers, and is reported to be more suitable for posterior regions with strong chewing forces[24]. Considering this information, in this study, traditional glass ionomer (IONOFIL U) and composite (SDR PLUS U) materials were selected along with hybrid materials such as compomers (DYRACT XP), giomers (BEAUTIFIL BULK), and glass hybrid (EQUIA FIL) restorative materials for comparing ion release.

Karakaş and Kuden, in their study in 2022, investigated the ion release of Alkasite, Activa, Equia Forte, and Zirconomer, fluoride-releasing restorative materials, after being immersed in beverages with different pH values. They evaluated the chemical composition of the four restorative materials using SEM/EDS spectrum and found that carbon (C), oxygen (O), sodium (Na), aluminum (Al), silicon (Si), calcium (Ca), and F ions were released in all materials. The presence of the P element was observed in all materials except compomer. It was reported that coffee significantly reduced the F ratio in Alkasite. Coffee and cola reduced the Na ratio in Alkasite. Coffee and saliva reduced the F and Na ratios in Activa. The C, O, Na, and Al ratios in Equia Forte significantly decreased in all liquids. Cola and saliva significantly increased the F ratio in Equia Forte, while coffee significantly increased the P ratio in Equia Forte. Coffee and cola significantly reduced the F ratio in Zirconomer, and coffee reduced the Na ratio in Zirconomer[25]. In this study, the release of all mentioned elements was observed in the materials, and the release of the P element was not observed only in the compomer (DYRACT XP) material. In addition to the ion release mentioned in the study, strontium ion release was observed in traditional glass ionomers (IONOFIL U), giomers (BEAUTIFIL BULK), and compomer (DYRACT XP) materials, zirconium ion release was observed in traditional glass ionomers (IONOFIL U) and giomer (BEAUTIFIL BULK) materials, and barium and nickel ion release was observed in bulk flowable composite (SDR PLUS U) and glass hybrid (EQUIA FIL) restorative materials.

Since bacterial infection is the main cause of secondary caries, the development of dental materials with antibacterial properties has gained great interest. Studies have shown that fluoride compounds exhibit clear antibacterial effects and can act through various mechanisms, including increasing the permeability of bacterial cell membranes and directly inhibiting the action of enzymes. Therefore, fluoride compounds are widely used as antibacterial restorative materials to develop new composite resins. Currently, many fluoride-releasing composite resins containing fluoride-alumino-silicate glass (FAG), calcium fluoride (CaF_2), or ytterbium fluoride (YbF_2) have been developed. However, most of them have shown very low fluoride release content and therefore minimal caries-preventive properties. It is believed that there is still a long way to go to develop new composite resins with effective fluoride release and antibacterial properties[26]. In this study, we compared the fluoride ion release from the bulk flowable composite material SDR plus and found that fluoride ion release occurred, but it was the lowest compared to other materials.

In a study conducted by Liyuan et al. in 2021, a new composite resin containing F-ZrO2 (Fluoride-Zirconium oxide) was developed, and its various properties were evaluated. This new composite resin was mainly reported to exhibit suitable antibacterial effects by releasing fluoride. Furthermore, a significant relationship was shown between fluoride release and antibacterial activity of F-ZrO2 powders. In fact, it has been reported that the antibacterial mechanism of fluoride compounds is a result of the diffusion of fluoride ions. Based on this, F-ZrO2 powders are believed to have the potential to release ions and prevent bacterial growth when in contact with bacteria. It has been proven that zirconium, as a heavy metal, has a strong capacity to absorb fluoride in a liquid environment acting as fluoride receptors. However, such heavy metal chelates have received little attention in dental materials. Both quantitative and qualitative analyses have shown that the composite resin filled with 20% F-ZrO2 powders exhibited the best antibacterial property against the viability of S. mutans, which is consistent with fluoride release. Therefore, 20% F-ZrO2 powders were selected as the filler material to develop a new composite resin. The antibacterial effect of the F-ZrO2-filled composite resin increased with the increase of F-ZrO2 filler content. The highest fluoride release was observed on the first day, mainly from the surface of the composite resin. The fluoride release rate decreased in the following days[27].

According to the findings of Aishwarya et al.'s study published in 2022, it has been reported that giomers, glass ionomers, and compomers release fluoride in artificial saliva and release more fluoride when subjected to various fluoride doses. To evaluate the changes in fluoride release as a result of dental hygiene practices, fluoride toothpaste was applied to the samples every day for 15 days. Fluoride varnish was applied only once to measure the effectiveness of professional prophylaxis. During the first 15 days of the study, glass ionomer cement released the highest amount of fluoride, followed by giomer and then compomer. It was reported that compomers showed the least increase in fluoride content when exposed to fluoride toothpaste[28]. In this study, the ranking of fluoride ion release on the first day was traditional glass ionomer cement (IONOFIL U) > compomer (DYRACT XP) > giomer (BEAUTIFIL BULK), while on the 14th day, it changed to traditional glass ionomer cement (IONOFIL U) > giomer (BEAUTIFIL BULK) > compomer (DYRACT XP). However, the highest percentage of change in fluoride ion release from day 1 to day 35 was observed in the giomer (BEAUTIFIL BULK) material.

According to Wiegand et al., the material's initial fluoride release capacity generally affects the amount of fluoride released after exposure to fluoride sources. In addition, glass ionomer materials, which consist of fluoride-containing glass called polycarboxylic acid and fluorosilicate, interact with acids and bases. Therefore, glass ionomer materials release higher levels of fluoride[29]. In this study, the highest fluoride ion release on the 1st and 14th day was observed in traditional glass ionomer cement (IONOFIL U), while on the 35th day, the highest release was observed in the glass hybrid (EQUIA FIL) restorative material. The lowest percentage of change in fluoride ion release from day 1 to day 35 was observed in the glass hybrid (EQUIA FIL) restorative material.

According to Poggio et al., the term "burst effect" is used to describe the greater amount of fluoride released from glass ionomer cement within the first 24 hours as a result of rapid dissolution from the outer surface to the solution[30]. The fluoride release of all evaluated restorative materials significantly increased after the application of fluoride varnish. The highest increase in fluoride was observed in glass ionomer cement after exposure to fluoride varnish[28]. In a study conducted by Marija et al., the fluoride release of composite, giomer, and conventional glass ionomer was compared. They reported that giomer released less fluoride ions than composite after recharging. This can be explained by the presence of pre-reacted glass ionomer particles on the surface of the giomer. Alkasite composite (Cention), Giomer (Beautiful II), and conventional glass ionomer cement (Fuji IX Extra) can be recharged with fluoride ions topically applied with NaF gel. Traditional composite (Filtek Z250) did not show the ability to recharge. Alkasite composite, giomer, and conventional glass ionomer cement showed better recharge potential. The application of dental adhesive systems has been reported to interfere with fluoride recharge and release[31].

Unlike the internal surface of the restoration adjacent to the cavity wall, the external restoration surface is exposed to saliva and repeated acidic changes due to the dynamic oral environment, which increases the surface porosity of the material over time. These pores can serve as a pathway for fluoride uptake and can even perform surface absorption due to increased surface roughness[32]. Adhesive systems not only decrease the concentration of adsorbed fluoride but also the composition of resin systems may play a role in this decrease. The monomers Bis-EMA, Bis-GMA, TEGDMA, and UDMA in the composite material (Filtek Z250) are hydrophobic and reported to have a negative affinity for water absorption. The alkasite material (Cention) mainly contains hydrophobic monomers and also a hydrophilic monomer, PEG-400 DMA, which can explain significantly higher fluoride re-release in alkasite composite compared to other investigated materials[33].

In a study conducted by Gururaj et al., the release of fluoride ions from five different restorative materials (traditional glass ionomer cement - Fuji VII, resin-modified glass ionomer cement - Vitremer, polyacid-modified composite resin - Dyract, fluoride-containing composite - Tetric Ceram, giomer - Beautifil) was evaluated. As a result, they found that traditional and resin-modified glass ionomer cements released a higher amount of fluoride ions[34].

CONCLUSIONS

In the research, the highest average fluoride release value among the restorative materials used was observed in the glass ionomer (IONOFIL U) group, followed by glass hybrid (EQUIA FIL) restorative material, compomer (DYRACT XP), giomer (BEAUTIFIL BULK), and bulk flowable composite (SDR PLUS U) material, respectively. It was determined that all materials released the highest amount of fluoride ions on the first day, gradually decreasing over time. While the highest fluoride ion release occurred on the first day in the ionofil (CGIC) group, the lowest fluoride ion release was observed on the 35th day in the SDR Plus U (COMPOSITE) group. Based on the findings obtained from the research, it is considered that glass ionomer cements (IONOFIL U) and glass hybrid (EQUIA FIL) restorative materials are particularly suitable for use in patients with high caries risk due to their higher fluoride release and less decrease in fluoride release over time compared to other materials. Although laboratory studies are recommended to investigate information related to ion release, the real performance of restorative materials can only be determined through long-term clinical studies. Therefore, it is recommended to conduct more clinical research studies with additional parameters to evaluate these properties under in vivo environmental conditions.

ACKNOWLEDGEMENTS AND FUNDING

We acknowledge with gratitude the support of the Istanbul University Scientific Research Projects Unit (TDH-2022-39028),

CONFLICT OF INTERESTS

No conflicts of interest present.

REFERENCES

1- Pitts NB. Are we ready to move from operative to non-operative/preventive treatment of dental caries in clinical practice? Caries Res 2004;38:294–304.
2- US Department of Health and Human Services. Oral Health in America: A Report of the Surgeon General. Rockville: National Institute of Dental and Craniofacial Research, National Institutes of Health 2000;308.
3- Rober H, Selwitz DDS, Amid I, Nigel B, Pitts BDS. Dental caries. Lanccet 2007;369:51-59.
4- Jaime AC, Branca HO, Ana P, Pires S, Livia M, Andaló T. Are fluoride releasing dental materials clinically effective on caries control? Dental Materials 2016;32(3)323-333.
5- Sufyan G, Pekka KV, Lippo L. Characterization of fluoride releasing restorative dental materials. Dental Materials Journal 2018;37(2):293–300.
6- Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. Biomaterials 2003;24:2451–2461.
7- Itota T, Carrick TE, Yoshiyama M, McCabe JF. Fluoride release and recharge in giomer, compomer and resin composite. Dent Mater 2004;20:789–795.
8- Caldeira ÉM, Osório A, Oberosler ELC, Vaitsman DS, Alviano DS, da Cunha GNM. Antimicrobial and fluoride release capacity of orthodontic bonding materials. J Appl Oral Sci 2013;21(4):327–34.
9- Neelakantan P, John S, Anand S, Sureshbabu N, Subbarao C. Fluoride release from a new glass-ionomer cement. Oper. Dent 2011;36(1):80-85.
10- Tiwari S, Kenchappa M, Bhayya D, Gupta S, Saxena S, Satyarth S, et al. Antibacterial activity and fluoride release of glass-ionomer cement, compomer and zirconia reinforced glass-ionomer cement. J Clin Diagn Res 2016;10(4):ZC90.

11- Marsh PD. Controlling the oral biofilm with antimicrobials. J Dent 2010;38:S11–5.
12- 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(03):245- 50.
13- De Moor RJ, Verbeeck RM. Effect of encapsulation on the fluoride release from conventional glass ionomers. Dent Mater 2002;18:370-5.
14- Kishore G, Sai-Sankar A, Pratap GM, Sridhar M, Pranitha K, Sai KV. Comparative evaluation of fluoride releasing ability of various restorative materials after the application of surface coating agents–an in-vitro study. J Clin Diagn Res 2016; 10(12):ZC38.
15- Poggio C, Andenna G, Ceci M, Beltrami R, Colombo M, Cucca L. Fluoride release and uptake abilities of different fissure sealants. J Clin Exp Dent 2016;8(3):e284-9.
16- Abudawood S, Donly KJ. Fluoride release and re-release from various esthetic restorative materials. Am J Dent. 2017;30(1):47-51.
17- Suebsureekul P, Viteporn S. Release of fluoride from orthodontic adhesives and penetration into enamel. J Orofac Orthop 2017;78(3):185-92.
18- Itota T, Carrick TE, Rusby S, Al-Naimi OT, Yoshiyama M, McCabe JF. Determination of fluoride ions released from resin-based dental materials using ion-selective electrode and ion chromatograph. J Dent 2004;32:117–22.
19- Vermeersch G, Leloup G, Delmée M, Vreven J. Antibacterial activity of glass-ionomer cements, compomers and resin composites: Relationship between acidity and material setting phase. J Oral Rehabil 2005;32:368–74.
20- Feiz A, Nicoo MA, Parastesh A, Jafari N, Sarfaraz D. Comparison of antibacterial activity and fluoride release in tooth-colored restorative materials: Resin-modified glass ionomer, zirconomer, giomer, and cention N. Dent Res J 2022;14;19:104.
21- Nigam AG, Jaiswal JN, Murthy RC, et al. Estimation of fluoride release from various dental materials in different media-an in vitro study. Int J Clin Pediatr Dent 2009;2:1–8.
22- Bayrak GD, Sandalli N, Selvi KS, Topcuoglu N, Kulekci G. Effect of two different polishing systems on fluoride release, surface roughness and bacterial adhesion of newly developed restorative materials. J Esthet Restor Dent 2017;29(6):424-3.
23- Ruengrungsom C, Burrow MF, Parashos P, Palamara JEA. Evaluation of F, Ca, and P release and microhardness of eleven ion-leaching restorative materials and the recharge efficacy using a new Ca/P containing fluoride varnish. J Dent 2020;102,103474.
24- Oliveira LC, Dos Santos PH, Ramos FSS, Moda MD, Briso ALF, Fagundes TC. Wear, roughness and microhardness analyses of single increment restorative materials submitted to different challenges in vitro. Eur Arch Paediatr Dent 2020;22,247-255.
25- Karakaş SN and Kuden C. AFM and SEM/EDS characterization of surfaces of flourine-releasing bulk-fill restorative materials aged in common liquids. Journal of Oral Science 2022;64(3):202-207.
26- Francois P, Fouquet V, Attal JP, Dursun E. Commercially available fluoride- releasing restorative materials: a review and a proposal for classification, Materials 2020; 13(10):2313.
27- Zheng L, Li K, Ning C, Sun J. Study on antibacterial and fluoride-releasing properties of a novel composite resin with fluorine-doped nano-zirconia fillers. J Dent 2021; 113:103772.
28- 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):736-738.
29- Wiegand A, Buchalla W, Attin T. Review on fluoride-releasing restorative materials–fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. Dent Mater 2007;23(3):343–362.
30- Poggio C, Andenna G, Ceci M, et al. Fluoride release and uptake abilities of different fissure sealants. J Clin Exp Dent 2016;8(3):e284–e289.
31- Kelić M, Kilić D, Kelić K, Šutej I, Par M, Peroš K, et al. The Fluoride Ion Release from Ion-Releasing Dental Materials after Surface Loading by Topical Treatment with Sodium Fluoride Gel. J Funct Biomater 2023;14(2):102.
32- Marovic D, Par M, Posavec K, Marić I, Štajdohar D, Muradbegović A, et al. Long-term assessment of contemporary ion-releasing restorative dental materials. Materials 2022; 15:4042.
33- Par M, Gubler A, Attin T, Tarle Z, Tarle A, Prskalo K, et al. Effect of adhesive coating on calcium, phosphate, and fluoride release from experimental and commercial remineralizing dental restorative materials. Sci. Rep 2022;12:10272.
34- Gururaj M, Shetty R, Nayak M, Shetty S, Kumar C. Fluoride releasing and uptake capacities of esthetic restorations. J Contemp Dent Pract. 2013; 14:887-91. 190.