Factors influencing fluoride release in atraumatic restorative treatment (ART) materials: A review

P.Divya Kumari[a], Shahnawaz Khijmatgar[a], Avidyuti Chowdhury[b], Edward Lynch[c], Chitta R. Chowdhury[a,*]

[a] Department of Oral Biology and Genomic Studies, A.B.Shetty Memorial Institute of Dental Sciences, Nitte Deemed to be University, Deralakatte, Mangalore, Karnataka, India
[b] Kings College London, Global Child Health Fund, England, UK
[c] Biomedical and Clinical Research, University of Nevada, Las Vegas, UNLV, USA

ABSTRACT

Objectives: The purpose of this article was to review the fluoride release and uptake ability of some restorative materials which are used for minimally invasive procedures.
Methods: The literature search on published researches and review articles were carried out by using PubMed, Trip and Cochrane library databases. The search terms used were fluoride, restorative materials, atraumatic restorative treatment or ART, glass ionomer or GIC, resin modified glass ionomer cement or RMGIC. The articles included were between 2000 and 2015.
Conclusion: Fluoride release varies with m factors including the type of restorative materials used and also the media in which it is stored. Fluoride uptake is dependent on the type of the cement and the availability of fluoride including fluoride releasing capacity in the material.

1. Introduction

Dental caries is a multifactorial disease condition involves cariogenic microorganisms such as *mutans streptococci* and *lactobacilli*.[1] These bacteria can be found in dental plaque on the tooth and gum, and can produce extracellular polysaccharides that assist bacterial adhesion.[1,2] Without cariogenic bacteria and fermentable carbohydrate the process of demineralisation process is not possible to start in order to produce acid, which is the cause of demininerlisation of dental hard tissue which leads to formation of a cavity, known as dental caries.[3–5]

Dental caries can be prevented by avoiding the favourable condition for de-mineralisation of hard tissues of tooth in the oral environment. Fluoride is the most beneficial topical agent, which exerts an anti-caries effect by means of several mechanisms including enhancing remineralisation and inhibiting microbial growth and their metabolism.[6–8] The availability of fluoride in the oral environment, such as saliva and crevicular areas can be provided from the external agents such as dentifrices and from specif type of restorative material, releases fluoride from it[9]

There are several restorative materials available in the market which include conventional glass-ionomer cements, resin modified glass-ionomer cements, compomers, composites and amalgams. Some restorative materials have the capacity of releasing fluoride in oral environment, which can help inhibit recurrent caries. The fluoride releasing capacity varies from one restorative material to the other and also depends on oral environment, such as pH of saliva.[10–12] It also depends on other factors such as, powder liquid ratio, constituents of restorative cement and ability to releasing of fluoride from the finasl set in oral environment of a patient.[13–15]

The aim and objective of this review was to discuss the fluoride release capacity from different dental restorative materials, such as glass ionomer cements (GIC) and resin modified glass ionomer cements (RMGIC), compomeres, and their ability of fluoride releasing capacity of in oral environment.

A significant number of original research (in-vitro) and review papers on the fluoride releasing and recharging capacity in dental restorative materials such as glass ionomer cements and resin modified glass ionomer cement were identified through PubMed, Trip and Cochrane library published between 2000 and 2015. Those papers studied and summarized on the issue of fluoride releasing capacity in restorative materials in different media at different intervals of time, including pH of the envornment. Also, fluoride uptake due to topical applications and re-release into the media from dental materials were included in this review paper. This paper also discusses the various

Table 1
Fluoride releasing capacity of marketed Conventional GIC: commonly used brands.

Storage Medium	Vo l(ml)	Sample dimension d x h (mm)	Fluoride released (ppm), [µg/cm^2][a]				pH	Name of CGIC	Ref
			1 day	7 days	14–15 days	28–30 days			
DIW	01	4x8	69.92	15.48	8.34	–	NM	GC Fuji VII	38
	01	4X8	22.05	3.64	2.36	–	NM	GC Fujji IX GP fast	39
	01	4X8	53.82	5.29	4.29	–	NM	GC Fujji IX GP extr	39
	01	4X8	31.62	5.541	4.64	–	NM	GC Fuji II LC	39
	25	5 x 2	7.184	1.054	0.811	–	4	NM	17
	10	5 x 2.5	9.991	1.512	0.671	–	NM	CG2	23
	10	5 x 3	1.22	0.29	0.20	0.16	NM	KME	34
	30	6 x 2	18.9	1.27	–	–	NM	Fuji II	35
	30	6 x 2	8.94	0.35	–	–	NM	Fuji IX	35
	05	5 x 2	1.6	2.6	0.8	1.0	NM	GC Fuji II	36
	05	5 x 2	2.5	2.0	1.1	1.0	NM	GC FujiVII	36
	05	5 x 2	1.4	1.0	0.6	0.7	NM	GC Fuji IX	36
	3	8.4x2.6	27.62	5.19	4.90	2.35	NM	Ionofil Plus	36
	3	8.4x2.6	25.56	3.95	4.00	1.86	NM	Fuji IX	33
	05	8.6x1.65	18.6	–	8.35	–	NM	Shofu-FX	33
	20	9 x 2	3.38	5.51	1.42	1.85	NM	GC	24
	05	10x1	24.04	13.08	19.44	11.81	NM	Ketac-Fil Plus aplicap	16
	02	**5 x 2**	**14.21**	**1.84**	**1.10**	–	NM	Ketac-Fil Plus	7
AS	02	3x2.7	23.7	36.1	31.5	22.4	05	GI-1	44
	02	3x2.7	2.3	3.9	3.3	2.3	05	Ketac-Molar	44
	02	3x2.7	2.0	3.1	2.6	1.7	05	FX	44
	02	3x2.7	14.7	22.5	18	10.9	05	Hi-Dense	44
	10	5 x 2.5	6.975	1.062	0.552	–	NM	CG2	44
	05	5 x 2.5	1.14	1.79	1.74	1.16	NM	Fuji VII	24
	05	8.6x1.65	8.22	–	5.11	–	07	Shofu-FX	24
	25	10x2	7.35	0.81	–	0.64	07	Fuji II	22
	25	10x2	18.37	2.02	–	1.597	07	Fuji II	22
Other	10	5 x 2.5	22.29	3.533	1.31	–	Lacticacid	CG2	23
	02	5 x 3	–	–	59.03	–	4.3	Fuji IX	27
	02	5 x 3	–	–	56.53	–	4.6	Fuji IX	27
	02	5 x 3	–	–	55.44	–	5.0	Fuji IX	27
	02	5 x 3	–	–	53.12	–	5.5	Fuji IX	27
	02	5 x 3	–	–	52.48	–	6.2	Fuji IX	27
	02	5 x 3	–	–	66.70	–	4.3	Fuji II	27
	02	5 x 3	–	–	65.72	–	4.6	Fuji II	27
	02	5 x 3	–	–	62.81	–	5.0	Fuji II	27
	02	5 x 3	–	–	59.38	–	5.5	Fuji II	27
	02	5 x 3	–	–	55.63	–	6.2	Fuji II	27
	05	8.6x1.65	17.53	–	15.58	–	4.3	Shofu-FX	24
	02	8.6x1.65	21.89	7.80	6.09	–	4.3–7	Vidrion R	47
	02	8.6x1.65	45.65	17.93	16.08	–	4.3–7	Vitro Fil	47
	02	8.6x1.65	27.68	15.14	12.70	–	4.3–7	Vitro Molar	47
	02	8.6x1.65	27.03	12.73	9.97	–	4.3–7	Bioglass R	47
	02	8.6x1.65	18.50	5.38	3.69	–	4.3–7	Ketac Fil	47

Where, NM: Not mentioned, CGIC: Conventional glass ionomer cement, RMGIC: Resin modifies glass ionomer cement, AS: Artificial saliva, DIW: De-ionised water, Ref: Reference.

[a] Blue highlights: Values are in [µg/cm^2].

factors influencing the fluoride release/uptake capacity in the materials.

2. Fluoride release capacity from restorative materials

Fluoride release from dental restorative materials can be part of the setting reaction and can also be added to the formulation with the specific intension to obtain fluoride releasing potential. The released fluoride from the material can protect the tooth tissues from demineralization in the region near to the restorative material (inter-phase areas). Fluoride precipitated from a restorative material and released in the oral environment in the form of CaF_2, which serves as a reservoir of fluoride when the pH drops. Fluoride release from the restorative material after application of fluoridated agents may occur partly by washout of the fluoride ion which is retained on the surface and in the porous regions of restorative materials, otherwise, they may be incorporated into the matrix. These fluoride releasing restorative materials act as a fluoride reservoir to maintain an increased level of fluoride around restorations and thus prevent or inhibit formation of secondary caries.[16–18]

2.1. Conventional glass ionomer cement (GIC)

Glass ionomer cements (Glass polyalkenoate cements) is the generic name for the materials, which are based on the reaction of glass powder and polyacrylic acid. GIC's are widely used in restorative dentistry as luting cements, bases of a prepared tooth cavity, anterior and posterior filling materials, including bone cements. They are often tooth-coloured materials that bond chemically to dental hard tissues and release fluoride for a longer period.[6]

Glass ionomers were developed and patented in the 1960s by Alan Wilson and co-workers at the laboratory of the Government Chemist in London. They were prepared by Wilson and co-workers, had adequate handling and working characteristics but slow setting characteristics along with poor hydrolytic stability which disqualified them for widespread clinical usage.[19]

Conventional glass ionomer cements were then introduced in 1972 by Wilson and Kent. They were derived from aqueous polyalkenoic acid

such as polyacrylic acid and a glass component that was usually fluoroaluminosilicate. When the powder and liquid were mixed together, an acid-base reaction occurred where; the acid attacked the glass network which resulted in the release of cations, mainly Al^{3+} and Ca^{2+} or Sr^{2+}. Later, these cations serve to form salt bridges between the polyacid chains and result in the formation of a silica hydrogel, However the calcium polyacrylate formation exhibits faster reaction kinetics than that of aluminum polyacrylate. As the metallic polyalkenoate salt begins to precipitate, gelation begins and proceeds until the cement sets hard. Glass ionomers bond to tooth structure undergoes several mechanisms including chelating the carboxyl groups of the polyacrylic acid with the calcium in the apatite of the enamel and dentine. Its physical properties can be modified by varying the powder – liquid ratio or chemical formulation.[20,21]

It has been determined in previous studies that conventional glass ionomers have the capacity of a slow releasing potential and steady flow-rate of the fluoride ions from the sample into the liquid medium.[10,12,22] Two mechanisms have been proposed by which fluoride may be released from glass-ionomers into the medium. One mechanism is a short-term reaction, which involves rapid dissolution from the outer surface into solution. The second is a long term reaction, which involves the sustained diffusion of ions through the bulk cement.[18,23] Also, the fluoride releasing capacity of conventional GIC varies from one medium to other.[24] Few studies have shown that fluoride release from the GICs depends on the type of storage media used, which may either inhibit or benefit fluoride release from the cement to the media.[25,26] Conventional glass ionomer cement released higher concentrations of fluoride in deionised water than in artificial saliva, and the capacity for fluoride release was higher in a lower pH solution.[23,24,27–29] Table 1 highlights the fluoride releasing capacities in different media at different intervals of time.

GIC releases the highest amount of fluoride in the first 24 h during the early setting time and this phenomenon is called the initial bust.[3,37] The reason behind the initial bust is due to surface wash off effect.[23,32,33] The initial bust of fluoride is important for remineralisation as well as for the reduction of viability of microorganisms that may have been left in the carious dentine, thus providing higher amounts of fluoride when it is most needed to help prevent secondary caries.[16] The capacity of fluoride release starts to decrease after 24–48 h and maintains a fairly constant level within 10–20 days.[34] This reduction of fluoride releasing capacity after a week is from a balance between the erosive leaching of glass particles in the bulk of the cement and diffusion of the leached fluoride through the cement matrix. Long term fluoride release occurs in smaller amount in conventional GIC which ranges from several months to five years.[17]

In vitro, fluoride release from different brands of conventional GIC (5 - 6 mm in diameter, 2–3 mm in length) in the first 24 h ranged from 1.22 ppm to 18.9 ppm, while another brand of a conventional GIC (8.4 mm in diameter, 2.6 mm in length) released fluoride ranging from 25.56 ppm to 27.62 ppm.[17,23,33,35,36] After the initial bust, the fluoride release slowed down gradually.[29] On the 7th day fluoride release ranged from 1 ppm to 1.5 ppm (5 - 6 mm in diameter, 2–2.5 mm in length) and 5.19 ppm to 3.95 ppm (8.4 mm in diameter, 2.6 mm in length).[17,23,33,35,36] After the 7th day, there was a prolonged long-term fluoride release. Different ranges of fluoride release were observed in different media; higher amounts of fluoride release occurred in acidic media, less in de-ionized media and lesser in artificial saliva, and also varied with different pH of the media.[17,37] A previous study showed the fluoride released by one conventional GIC (5 mm × 2.5 mm) in the first 24hrs to be 9.99 ppm in a de-ionized medium, 6.98 ppm in artificial saliva and 22.29 ppm in lactic acid (pH 4).[17] The difference was due to the different type of storage media. A low pH environment accelerated the amount of fluoride released from this GIC.[25]

2.2. Resin-modified glass ionomer cement (RMGIC)

Glass ionomer materials have some disadvantages such as short working time, long setting time, susceptibility to early moisture and salivary contamination, desiccation after setting and brittleness. To overcome these limitations and to preserve fluoride release, with better mechanical and biological properties, resin-modified glass ionomer cement materials were introduced. RMGIC's are conventional GIC's with the addition such as hydroxyethylmethacrylate (HEMA).[16] During its initial setting, it undergoes both an acid-base ionomer reaction as well as curing by photo-initiation and a self-cure of methacrylate carbon double bonds.[38,39] HEMA in RMGIC slowly absorbs the water to allow for diffusion of fluoride ions into the medium.[31] RMGIC's have the capacity to release fluoride over 1–2.7 years.[18]

In one of the previous studies, it has been observed that RMGIC (Vitremer™, dimension 11 mm × 1.5 mm) released higher amounts of fluoride in demineralising (pH 4.3) and remineralizing (pH 7) solutions in the first two days, and thereafter it slowly decreased its fluoride release.[37] Many studies reported that fluoride released from RMGIC was less than from conventional GIC, and this is because the resin network present in the RMGIC can reduce the diffusion of water into the cement.[16,24,29,39,40] On the other hand, RMGIC released more fluoride than a conventional GIC.[28] One of the previous studies also showed that under neutral pH conditions, the rate of fluoride release from a RMGIC (KetacFil) at 72hr was significantly slower at a pH of 4.[41] Table 2 highlights the fluoride releasing capacity in different media, in different intervals of time and in different media for RMGIC materials.

3. Fluoride recharge/re-release of restorative materials from topical application

The ability to take up and re-release fluoride to the oral environment when restorative materials are exposed to fluoridated products such as toothpaste, mouthwash and fluoride gel, is an important property of some restorative materials.[33] When some restorative cements are exposed to topical fluoride, fluoride diffuses into the matrix material, increasing its reservoir of fluoride, from which it is subsequently and slowly leached to the oral environment or medium in which the restorative material is stored. This helps to strengthen the enamel adjacent to the restorative material. The absorption and re-release of fluoride might be partly determined by the permeability of the material. A complete permeable substance could absorb the ion deep into its bulk, while a relatively impermeable material can only absorb fluoride into the immediate subsurface.[22]

Re-charging is one of the important properties of GIC's. GIC when restored in a tooth releases the fluoride to the oral environment during the initial period of setting. Subsequently, it takes fluoride from the oral environment or from dentifrices, recharges with it and slowly re-releases with an increased quantity of fluoride to the oral environment.[32] This can help to avoid secondary caries and longetivity of the material.

Restorative materials with a higher fluoride releasing capacity also have a higher fluoride recharging ability.[22,30,42] Restorative materials with higher porosity allow deeper diffusion of the recharging agent. This permits a higher amount of fluoride storage in these restorative materials and subsequent re-release to the media. The tendency for the amount of fluoride re-released after recharge, increases with the age of the restorative material.[42]

Another research, found a higher amount of fluoride re-released when restorative materials were treated with toothpaste (1000 ppm) as compared to mouthwash (220 ppm).[39] Toothpaste is higher in viscosity than a mouth wash, which is difficult to wash out completely and may have remained trapped in the pores of these materials and could then release more fluoride on the first day after recharge. There is also a variation of the concentration of fluoride in the recharge agents.[39] Hence, fluoride re-released from the restorative material treated with toothpaste showed more release compared to that with mouthwash

Table 2
Fluoride releasing capacity of marketed different Resin-Modified GIC: commonly used brands.

Storage Medium	Vo l(ml)	Sample dimention d x h (mm)	Fluoride released (ppm), [µg/cm²][a]					pH	Brand name of RMGIC	Ref
			1 day	7 days	14–15 days	21 days	28–30 days			
DIW	10	5 x 2.5	6.014	1.037	0.753	–	–	NM	Ketac N100	23
	10	5 x 3	12.33	1.37	0.80	–	0.80	NM	Rely x luting 2	34
	10	5 x 3	4.35	0.66	0.40	–	0.39	NM	Vitremer	34
	05	8.6x1.65	8.08	–	5.59	–	–	NM	Fuji-II-LC	24
	20	9 x 2	2.88	2.06	2.02	–	2.19	NM	Ketac^TM N100	16
	04	11x1.5	41.5	3.21	2.24	–	–	NM	Vitremer™	37
	02	5 x 2	**8.56**	**1.51**	**1.23**	–	–	NM	vitremer	7
	02	5 x 2	**4.80**	**0.78**	**0.48**	–	–	NM	Fuji II LC	7
AS	02	3x2.7	22.1	40.2	37.2	30.6	25.6	05	Photac-Fil	44
	02	3x2.7	9.1	14.9	12.2	8.6	7.0	05	Photac-Fil Quick	44
	10	5 x 2.5	5.012	–	0.602	–	–	NM	Ketac N100	23
	05	5 x 2	1.17	–	2.49	2.15	1.86	NM	Vitrimer 3M ESPE	36
	05	8.6x1.65	6.59	–	2.04	–	–	07	Fuji-II-LC	24
	25	10x2	4.35	0.52	–	–	0.43	07	Fuji II LC	22
	25	10x2	0.81	0.84	–	–	0.655	13	Fuji II LC	22
Other	10	5 x 2.5	16.088	2.825	1.552	–	–	Lacticacid	Ketac N100	23
	05	8.6x1.65	13.52	–	11.83	–	–	4.3	Fuji-II-LC	24
	04	11x1.5	79.86	8.24	5.047	–	–	Lacticacid	Vitremer™	37
	02	8.6x1.65	26.64	8.16	5.82	–	–	4.3–7	Vitremer	47
	02	8.6x1.65	42.65	10.65	5.82	–	–	4.3–7	Vitro fil LC	47
	02	8.6x1.65	28.75	12.75	10.39	–	–	4.3–7	Resiglass	47

Where, NM: Not mentioned, CGIC: Conventional glass ionomer cement, RMGIC: Resin modifies glass ionomer cement, AS: Artificial saliva, DIW: De-ionised water, Ref: Reference.
  [a] Blue highlights: Values are in [µg/cm²].

treatment.[33,39,43]

A study on the subject showed that fluoride released by restorative materials was maximal at 24 h and gradually decreased on the 7th day and 15th day. After application of 1.23% APF gel for 4 min, fluoride release was maximum on the 16th day and decreased on the 22nd and 30th days in the media (de-ionized water, artificial saliva and lactic acid), but not more than the initial burst.[44] RMGIC has a higher capacity to re-release fluoride immediately and 24 h after recharge than conventional GIC, but the initial fluoride release (initial burst) before treatment of recharge agent, was higher with the conventional GIC than the RMGIC.[23] Table 3 highlights the fluoride releasing capacities in different media and at different intervals of time.

A higher amount of fluoride is released by conventional GIC when it is exposed to neutral sodium fluoride and fluoridated dentifrices.[32] The cumulative fluoride released by GIC in artificial saliva in 28 days was 8.8 ppm without exposure to 2% NaF, 11.61 ppm when exposed to neutral 2% NaF, and 10.21 ppm when exposed to fluoridated dentifrices.[42] On the other hand the cumulative fluoride released by RMGIC in artificial saliva in 28 days was 2.31 ppm without exposure to 2% NaF, 2.41 ppm when exposed to 2% NaF, and 2.41 ppm when exposed to fluoridated dentifrices. Conventional GIC's released significantly higher amounts of fluoride than other restorative materials after it was exposed to 0.2% NaF for 5 min.[40]

One of the previous studies accesses the fluoride releasing capacity of CGIC and RMGIC before and after exposure to 1.23% APF gel for 4 min over 6 weeks. Fluoride releasing capacity was high for the first 24 h and thereafter the release rates continued to fall.[46] The mean levels of fluoride released after exposure to 1.23% APF gel were considerably

Table 3
Cumulative fluoride releasing capacity of ART materials with and without exposure of fluoride agent.

Type of ART	Storage Medium	Sample dimention d x h (mm)	Cumulative Fluoride release (ppm) [µg/cm²][a]					pH	Brand name of ART	Ref
			Without expose	With expose						
				2% NaF	F TP	F MW	APF gel			
CGIC	DIW	4 x8	**36.25**	–	**44.13**	**43.02**	–	NM	GC Fuji IX Fast	39
		4 x8	**72.52**	–	**86.95**	**84.77**	–	NM	GC Fuji IX extra	39
		4 x8	**50.68**	–	**67.38**	**64.38**	–	NM	GC Fuji II LC	39
		4 x8	**129.23**	–	**155.98**	**155.95**	–	NM	GC Fuji VII	39
	AS	3 x2.7	139.5	–	–	–	30.3	05	GI-1	44
		3x2.7	14.4	–	–	–	11.4	05	Ketac-Molar	44
		3 x2.7	11.5	–	–	–	26	05	FX	44
		3x2.7	79.4	–	–	–	20.3	05	Hi-Dense	44
		10x2	21.99	28.98	25.45	–	–	07	Fuji II	42
		10x2	8.8	11.61	10.21	——	–	07	Fuji II	42
RMGIC	DIW	4 x 8	4.75	–	12.79	10.53	–	NM	Dyract Extra	39
	AS	3 x2.7	155.7	–	–	–	85.5	05	Photac-Fil	44
		3x2.7	51.8	–	–	–	53.9	05	Photac-Fil Quick	44
		10x2	2.305	2.408	2.408	–	–	07	Fuji II LC	42
		10x2	5.3	6.96	6.5	–	–	07	Fuji II LC	42

Where, NM: Not mentioned, CGIC: Conventional glass ionomer cement, RMGIC: Resin modifies glass ionomer cement, AS: Artificial saliva, DIW: De-ionised water, Ref: Reference, NaF: Sodium fluoride, F TP: Fluoridated toothpaste, F MW: Fluoridated mouth wash.
  [a] Blue highlights: Values are in [µg/cm²].

lower than those immediately before immersion into the APF gel.[45] There are short-term fluoride reservoir effects following the use of APF gel, and also surface damage caused by this treatment.[46]

A scientific investigation reported that the cumulative fluoride released in de-ionized water during 86 days from CGIC (Fuji IX GP) was 1,363 ppm whilst that from RMGIC (Ketac N100) was 715.9 ppm.[40] The same order was seen after recharging with a 0.2% NaF solution for 5 min. Again, the fluoride release 24hrs from the recharge was lower than the initial burst. Cumulative fluoride release amounts after 5 days from CGIC and RMGIC in de-ionised water were 35% and 31% respectively of their initial 5 days cumulative fluoride release amounts.[39,40]

A previous study, evaluated the fluoride recharge potential in vitro over two years. RMGIC's (Vitremer and Photac-fil Aplicap) had a higher ability for initial fluoride release as well as a higher recharge potential.[47] In the case of the CGIC's, one of the brands, Chemfil, showed relatively low initial fluoride release but its recharge potential increased steadily where as another CGIC, Ketac-fil, showed opposite effects.[47]

4. Factors influencing the release or uptake of fluoride

There are several factors influencing the release/uptake of fluoride from the ART materials. Fluoride release from restorative materials is dependent on exposed surface area, not on weight of the sample.[48] Initial fluoride burst from restorative materials, especially GIC, is probably associated with release of fluoride which is loosely bound with cement and originates from the acid-base reaction between the glass and polyalkenoic acid.[16] The rate of fluoride release depends on several experimental and intrinsic variables such as media in which samples are stored, surface area exposed in media, temperature, pH of the medium, powder-liquid ratio of the material, method of mixing, resin matrix, solubility and porosity of the material.[18,23,24,29,41,48]

Fluoride releasing capacity from restorative materials in an acidic environment will be higher compared to those in a neutral pH environment. This is because, dissolution of the restorative material increases with decreasing pH. Release of fluoride from the all type of restorative materials was influenced by pH variation of the storage medium.[25,28,29,49–51] Many studies related to storage media to determine the fluoride release, confirmed that acidic solutions show more release of fluoride from the matrix of restorative materials than that in remineralizing solutions, water or artificial saliva.[23–25,28,29]

Higher amount of fluoride are released from restorative materials in de-ionized water (pH 7) than in artificial saliva (pH 7), indicating that fluoride release is significantly influenced by the ionic strength and composition of artificial saliva.[16,26,29,50] The nature of fluoride incorporated in restorative materials also affects the fluoride recharge ability and recharge potential of fluoride varies with the type of materials.[38] The fluoride recharge and re-release abilities of restorative materials depend on the composition of the material, on the frequency of the fluoride exposure, as well as the type and concentration of fluoridating agents.[18,52] A higher porosity allows a deeper diffusion of the recharge agent into the restorative material and results in more fluoride storage and release.[37,41]

5. Conclusion

In conclusion, fluoride release varies with types of restorative material, their matrices, setting mechanisms, fluoride content, nature of fluoride incorporated into resin based materials, media in which it is stored, and how it is stored. Fluoride uptake will be dependent on the cement and the available type of fluoride.

Both CGIC and RMGIC show initial burst phenomena. A few studies showed more fluoride released from RMGIC than CGIC. However, most studies highlighted that CGIC released more fluoride than RMGIC. Fluoride released from resin based restorative materials is less because

of the resin content compared to CGIC's which act as a barrier for fluoride to diffuse through the medium. The fluoride releasing capacity of restorative materials into a medium is maximal in a pH cycling model and then less in de-ionized water and even less in artificial saliva. Materials which are predominantly a salt matrix such as CGIC's and RMGIC's are more sensitive to changes in pH.

The large differences of fluoride release and recharge from the different restorative materials reported in studies is due to different methodology used including sample dimensions, types of storage media, duration of storage, pH of the storage media, volume of storage media and methods used to measure the fluoride released.

Conflicts of interest

Nothing to disclose.

References

1. Klai S, Altenburger M, Spitzmüller B, Anderson A, Hellwig E, Al-Ahmad A. Antimicrobial effects of dental luting glass ionomer cements on Streptococcus mutans. *Sci World J.* 2014;2014:1–7. https://doi.org/10.1155/2014/807086.

2. Kumar M, Mithun Pai BH, Prashant GM, et al. Antibacterial properties of fluoride releasing glass Ionomer cements (GICs) and pit and fissure sealants on Streptococcus mutans. *Int J Clin Pediatr Dent.* 2010;3:93–96.

3. Duque C, Negrini TD, Hebling J, Spolidório DM. *Inhibitory Activity of Glass-Ionomer Cements on Cariogenic Bacteria.* 30. Operative Dentistry-University of Washington; 2005:636.

4. Islam B, Khan SN, Khan AU. Dental caries: from infection to prevention. *Med Sci Monit.* 2007;13:RA196–203.

5. Al-Naimi OT, Itota T, Hobson RS, McCabe JF. Fluoride release for restorative materials and its effect on biofilm formation in natural saliva. *J Mater Sci Mater Med.* 2008;19:1243–1248.

6. Frencken JE, Leal SC, Navarro MF. Twenty-five-year atraumatic restorative treatment (ART) approach: a comprehensive overview. *Clin Oral Investig.* 2012;16:1337–1346.

7. Neelakantan P, John S, Anand S, Sureshbabu N, Subbarao C. Fluoride release from a new glass-ionomer cement. *Operat Dent.* 2011;36:80–85.

8. Vermeersch G, Leloup G, Vreven J. Fluoride release from glass–ionomer cements, compomers and resin composites. *J Oral Rehabil.* 2001;28:26–32.

9. Naoum S, Martin E, Ellakwa A. Long-term fluoride exchanges at restoration surfaces and effects on surface mechanical properties. *ISRN Dent.* 2013;2013:579039.

10. Mazzaoui SA, Burrow MF, Tyas MJ. Fluoride release from glass ionomer cements and resin composites coated with a dentin adhesive. *Dent Mater.* 2000;16:166–171.

11. Santos RL, Pithon MM, Fernandes AB, Carvalho FG, Cavalcanti AL, Vaitsman DS. Fluoride release/uptake from different orthodontic adhesives: a 30-month longitudinal study. *Braz Dent J.* 2013;24:410–414.

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 Dermatol.* 2010;4:245–250.

13. Tiwari S, NaNDlal B. Invitro evaluation of fluoride release from hydroxyapatite reinforced glass ionomer with or without protective coating. *J Indian Soc Pedod Prev Dent.* 2016;10:ZC73.

14. Lin YC, Lai YL, Chen WT, Lee SY. Kinetics of fluoride release from and reuptake by orthodontic cements. *Am J Orthod Dentofacial Orthop.* 2008;133:427–434.

15. Han L, Li M, Niano K, Okamoto A, Honda N, Iwaku M. Effect of fluoride mouth rinse on fluoride releasing and recharging from aesthetic dental materials. *Dent Mater J.* 2002;21:285–295.

16. Upadhyay S, Rao A, Shenoy R. Comparison of the amount of fluoride release from nanofilled resin modified glass ionomer, conventional and resin modified glass ionomer cements. *J Dent.* 2013;10:134.

17. Tiwari S, Nandlal B. Comparative evaluation of fluoride release from hydroxyapatite incorporated and conventional glass ionomer cement: an in vitro study. *J Indian Soc Pedod Prev Dent.* 2012;30:284.

18. Dionysopoulos D. The effect of fluoride-releasing restorative materials on inhibition of secondary caries formation. *Fluoride.* 2014;47:258–265.

19. Da Mata C, Allen PF, Cronin M, O'mahony D, McKenna G, Woods N. Cost-effectiveness of ART restorations in elderly adults: a randomized clinical trial. *Community Dent Oral Epidemiol.* 2014;42:79–87.

20. Bresciani E. Clinical trials with Atraumatic Restorative Treatment (ART) in deciduos and permanent teeth. *J Appl Oral Sci.* 2006;14:14–19.

21. Schriks MC, Van Amerongen WE. Atraumatic perspectives of ART: psychological and physiological aspects of treatment with and without rotary instruments. *Community Dent Oral Epidemiol.* 2003;31:15–20.

22. Rama Rao SB, Patri G, Agnihotri Y, Balagopal S. Fluoride and restorative materials. *Int. J. Contemp. Dent.* 2011;2:159–164.

23. Jingarwar MM, Pathak A, Bajwa NK, Sidhu HS. Quantitative assessment of fluoride release and recharge ability of different restorative materials in different media: an in vitro study. *J Clin Diagn Res.* 2014;8:31–34.

24. Nigam AG, Jaiswal JN, Murthy RC, Pandey RK. Estimation of fluoride release from various dental materials in different media—an in vitro study. *Int J Clin Pediatr Dent.* 2009;2:1–8.

25. Yoda A, Nikaido T, Ikeda M, Sonoda H, Foxton RM, Tagami J. Effect of curing

method and storage condition on fluoride ion release from a fluoride-releasing resin cement. *Dent Mater J.* 2006;25:261–266.

26. Hammouda IM, Al-Wakeel EE. Effect of water storage on fluoride release and mechanical properties of a polyacid-modified composite resin (compomer). *J Biomed Res.* 2011;25:254–258.

27. Bahadure RN, Pandey RK, Kumar R, Gopal K, Singh RK. An estimation of fluoride release from various dental restorative materials at different pH: in vitro study. *J Indian Soc Pedod Prev Dent.* 2012;30:122–126.

28. Selimović-Dragaš M, Hasić-Branković L, Korać F, et al. In vitro fluoride release from a different kind of conventional and resin modified glass-ionomer cements. *Bosn J Basic Med Sci.* 2013;13:197.

29. Silva KG, Pedrini D, Delbem AC, Cannon M. Microhardness and fluoride release of restorative materials in different storage media. *Braz Dent J.* 2007;18:309–313.

30. Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. *Biomaterials.* 2003;24:2451–2461.

31. Neelakantan P, John S, Anand S, Sureshbabu N, Subbarao C. Fluoride release from a new glass-ionomer cement. *Operat Dent.* 2011;36:80–85.

32. 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:ZC11–14.

33. Cildir SK, Sandalli N. Fluoride release/uptake of glass-ionomer cements and poly-acid-modified composite resins. *Dent Mater J.* 2005;24:92–97.

34. Basso GR, Della Bona Á, Gobbi DL, Cecchetti D. Fluoride release from restorative materials. *Braz Dent J.* 2011;22:355–358.

35. Shashibhushan KK, Basappa N, Reddy VS. Comparison of antibacterial activity of three fluorides-and zinc-releasing commercial glass ionomer cements on strains of mutans streptococci: an in vitro study. *J Indian Soc Pedod Prev Dent.* 2008;26:56–61.

36. Tiwari S, Nandlal B. Effect of nano-filled surface coating agent on fluoride release from conventional glass ionomer cement: an in vitro trial. *J Indian Soc Pedod Prev Dent.* 2013;31:91–95.

37. Garcez RM, Buzalaf MA, Araújo PA. Fluoride release of six restorative materials in water and pH-cycling solutions. *J Appl Oral Sci.* 2007;15:406–411.

38. 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;32:117–122.

39. Mousavinasab SM, Meyers I. Fluoride release and uptake by glass ionomer cements, compomers and Giomers. *Res J Biol Sci.* 2009;4:609–616.

40. Dionysopoulos D, Koliniotou-Koumpia E, Helvatzoglou-Antoniades M, Kotsanos N. Fluoride release and recharge abilities of contemporary fluoride-containing restorative materials and dental adhesives. *Dent Mater J.* 2013;32:296–304.

41. Carey CM, Spencer M, Gove RJ, Eichmiller FC. Fluoride release from a resin-modified glass-ionomer cement in a continuous-flow system: effect of pH. *J Dent Res.* 2003;82:829–832.

42. Rao BS, Moosani GK, Shanmugaraj M, Kannapan B, Shankar BS, Ismail PM. Fluoride release and uptake of five dental restoratives from mouthwashes and dentifrices. *J Int Oral Health.* 2015;7:1–5.

43. Mungara J, Philip J, Joseph E, Rajendran S, Elangovan A, Selvaraju G. Comparative evaluation of fluoride release and recharge of pre-reacted glass ionomer composite and nano-ionomeric glass ionomer with daily fluoride exposure: an in vitro study. *J Indian Soc Pedod Prev Dent.* 2013;31:234.

44. Pedrini D, Delbem AC, França JG, Machado TD. Fluoride release by restorative materials before and after a topical application of fluoride gel. *Pesqui Odontol Bras.* 2003;17:137–141.

45. Gao W, Smales RJ, Gale MS. Fluoride release/uptake from new glass ionomer cement used with the AT approach. *Am J Dent.* 2000;13:201–204.

46. Gao W, Smales RJ. Fluoride release/uptake of conventional and resin-modified glass ionomers, and compomers. *J Dent.* 2001;29:301–306.

47. Preston AJ, Agalamanyi EA, Higham SM, Mair LH. The recharge of esthetic dental restorative materials with fluoride in vitro—two years' results. *Dent Mater.* 2003;19:32–37.

48. Cabral MF, Martinho RL, Guedes-Neto MV, Rebelo MA, Pontes DG, Cohen-Carneiro F. Do conventional glass ionomer cements release more fluoride than resin-modified glass ionomer cements? *Restor Dent Endod.* 2015;40:209–215.

49. Can G, Kaplan R, Kalayci S. Fluoride release from polyacid modified composite (Compomer) in artificial saliva and lactic acid. *Arch Oral Sci Res.* 2009;5.

50. Barata TD, Bresciani E, Cefaly DF, Wang L, Navarro MF, Pereira JC. Influence of different storage solutions of fluoride release from glass ionomer cements. *Salusvita.* 2004;23:453–465.

51. Markovic DL, Petrovic BB, Peric TO. Fluoride content and recharge ability of five glassionomer dental materials. *BMC Oral Health.* 2008;8:21.

52. Itota T, Carrick TE, Yoshiyama M, McCabe JF. Fluoride release and recharge in giomer, compomer and resin composite. *Dent Mater.* 2004;20:789–795.