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Marginal leakage of various glass ionomer cements at tooth-restoration interfaces: A comparative study

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Abstract
It is well known that the marginal leakage is a major problem that occurs along the tooth-restoration interfaces, resulting from passage of bacteria, fluids, molecules and other ions. This *in-vitro* study was conducted to assess the marginal leakage of newly developed ceramic-reinforced glass ionomer cement and to compare it with other conventional-glass ionomer cements. A sample size of twelve sound bovine incisors was selected for the current study. Standardised box-shaped cavities were prepared on the proximal tooth surfaces mesially and distally. Samples were randomly divided into three groups and restored as follows: Group-I (Fuji IX GP), Group-II (AH Fil$^+$), and Group-III (GI Ceramic Reinforced Extra). The filled cavities were subjected to thermo-cycling process and then soaked in 0.5% methylene blue dye for testing the marginal leakage at the tooth-restoration interfaces. The dye penetration was assessed using a stereomicroscope and the degree of marginal leakage was evaluated using a specific scoring criteria as published previously. Statistically, the data were analysed using Kruskal-Wallis and Mann-Whitney U tests. GI Ceramic Reinforced Extra (Group-III) displayed the maximum leakage, followed by AH Fil$^+$ (Group-II). Further, the minimum value of leakage was measured in Fuji IX GP (Group-I). However, there were no statistically significant differences in the marginal leakage of the three groups ($p > 0.05$). It was concluded that all the tested materials showed a significant degree of leakage to some extent.

Keywords: Glass ionomer cements, marginal leakage, tooth-restoration interfaces, Fuji IX GP, AH Fil$^+$, GI ceramic reinforced extra

1. Introduction

A superior seal at tooth-restoration interfaces is an essential parameter to minimise the marginal leakage and thus to fulfil the requirement of restorative dentistry [1]. It is evident that the maximum adaptation of the restorative material to the walls of tooth cavity is considered mandatory for the longevity of restorations [1-3]. Moreover, the bonding mechanism has a vital role in enhancing the marginal sealing via formation a durable interlocking bond at the interfaces [4]. The ideal restorative material should have similar physical characteristics to dental tissues, in order to adhere well and not undergo dimensional changes in the oral environment [5].

Clinically, the major contributing factor that directly relates to the success or failure of the most restorative materials is the occurrence of marginal leakage [6-7]. The marginal leakage is defined as ‘‘undetectable passage of bacteria, fluids, chemical substances/molecules between the cavity walls and the restorative materials, which may cause hypersensitivity, recurrent caries, pulpitis, discoloration, post-operative sensitivity and even breakdown of the filling material itself’’ [8-9]. Several factors; including dimensional changes, temperature changes, mechanical stress and poor adaptation of restorative materials can participate in the gap formation at the interfaces partially or entirely [10].

It is well known that there is a strong correlation between the marginal leakage that occurs at the tooth-restoration interfaaces and the type/chemical composition of restorative materials. Thus, there are several methods to detect the gap formation at the interfaces; such as using of dyes, radioactive tracers, fluid filtration, air pressure, neutron activation analysis and scanning electron microscopy [11-14]. Among these methods, measurement of dye penetration at tooth-restoration interfaces is the most commonly used technique because of its low cost, fast technique, low molecular weight and does not need using of complex equipment [15-16]. Various dyes can be applied; including methylene blue, toluidine blue, India ink, basic fuschin, silver nitrate, crystal violet and fluorescin [15-17].

Glass ionomer cements (GICs) were developed in 1960s by Wilson and Kent at Laboratory of the London Government Chemist, and introduced commercially under the name of ASPA (Alumino-Silicate Poly-acrylic Acid) [18-20]. The GICs were synthesised as a hybrid material of silicate-cement powder and zinc polycarboxylate-cement liquid, thus they combine the benefits of silicate cement (fluoride release and translucent) and polycarboxylate cement (adhesion and biocompatibility) [18-21]. These properties make the GIC as an excellent restorative material for management of carious lesion.

However, the conventional-GICs are associated with some disadvantages; for instance high-moisture sensitivity, low-wear resistance, low-strength and slightly poor aesthetics [21-22]. Consequently, the production of newly developed GICs; such as resin-modified GICs (RMGIC), compomers, metal-reinforced GICs, nanoparticle titanium dioxide GICs, ceramic-reinforced GICs, bioactive-based GICs, has been achieved with maximum benefits in order to overcome the drawbacks that associated with these restorative materials and also to meet the ISO standards of water-based cements [20-23].

There is a huge interest in finding the perfect model of restorative materials with greater characteristics to minimise the gap formation at the interfaces and thus to reduce the potential of caries development. Hence, the current *in-vitro* study was carried out to assess the marginal sealing ability of the newly developed ceramic-reinforced GICs and to compare it with previously existing conventional-GICs using dye penetration method.

Materials and Methods

Samples Collection

Twelve non-carious bovine incisors were collected, cleaned and then stored at 4ºC in 0.2% thymol solution for the entire duration of the study.

Procedures of Marginal Leakage Test

Standardised box-shaped cavities with no mechanical retention were prepared on the proximal tooth surfaces medially and distally, using ISO #014 Straight-Fissure diamond bur and ISO #012 Inverted-Cone diamond bur with a high-speed, water-cooled hand-piece. The cavity measurement was 3 mm length, 2 mm width, and 2 mm depth. The specimens were divided into three groups (n = 4) randomly. The tested materials (Conventional-GICs) were applied following the manufacturer's instructions. The groups were restored with Fuji IX GP (Group-I), AH Fil+ (Group-II) and GI Ceramic Reinforced Extra (Group-III) respectively; details of used materials are listed in Table 1.

Immediately, all restored cavities were stored in distilled water at 37 ºC for 24 hr, in order to processing the setting reaction of GICs. Afterwards, they were subjected to thermo-cycling between 5-55ºC in water bath with dwell-time of 15 sec and transfer-time of 2-3 sec to simulate the oral condition. Following thermo-cycling process, the tooth apices were sealed with a melted sticky wax and 1 mm around the restoration margins was painted twice with nail polish to prevent dye penetration. Later on, all teeth were soaked in 0.5% methylene blue dye (Sigma-Aldrich, UK; P 101704491, LOT #BCBR1927V) for 24 hr and then washed under tap water to remove the excess dye.

Subsequently, the cavities were sectioned through the centre of the restorations, using a slow-speed water-cooled diamond disc (Struers, M0D08). The sectioned specimens were then viewed under a stereomicroscope (VWR-VistaVision Microscope) at magnification of x2.5 to measure the dye penetration grades. The extent of marginal leakage was evaluated by two clinicians independently; according to the following specific scoring criteria.

Score 0 = No dye penetration.

Score 1 = Dye penetration up to the first third of the prepared cavity wall.

Score 2 = Dye penetration up to the second third of the prepared cavity wall.

Score 3 = Dye penetration onto the entire prepared cavity wall.

Score 4 = Dye penetration onto the entire prepared cavity wall and the axial wall.

Statistical Analysis

The data were collected, tabulated and statistically analysed by non-parametric Kruskal-Wallis Test for multiple group comparison; using SPSS 24 (SPSS Inc., Chicago, USA) statistical analysis software. The pairwise comparison was also performed with Mann-Whitney U Test at a significance level of ($p < 0.05$).

Results

All the tested materials showed a significant degree of the marginal leakage to some extent; as seen in Figure 1 (a-c), and the corresponding scores are plotted in Figure 2. Kruskal-Wallis test for different groups confirmed that GI Ceramic Reinforced Extra (Group-III) had the maximum mean value of dye penetration which is 2.00±0.57, followed by AH Fil+ (Group-II) which is 1.57±0.97, and the minimum value was measured in Fuji IX GP (Group-I) which is 1.29±0.75. The P value was not significant for all GICs groups ($P = 0.213$); as tabulated in Table 2. Further, Mann-Whitney U Test was applied for paired comparison, as demonstrated no significant differences statistically between each two groups of the tested materials in terms of marginal leakage values ($P > 0.05$); as listed in Table 3.

Discussion

Nowadays, the chief concern in the field of restorative dentistry and dental materials is the marginal leakage formation at the tooth-restoration interfaces which still remains an extreme challenging for both researchers and clinicians. Actually, the marginal sealing of restorative materials to the cavity walls depends on material properties such as retention mechanism, compositions, additives incorporation and coefficient of thermal expansion [24-26]. In addition, the cavity size, geometry, bevelling placement and cutting angles at enamel prisms and dentinal tubules, all these factors have a direct impact on the quality of the marginal adaptation and could affect the development of secondary caries along the cavilty walls [27-29].

Fuji IX GP is a highly viscous material, developed by GC Corporation Tokyo, Japan, in 1990s. It has good adhesion to tooth surface, an adequate strength, and it can be finished/polished in one visit. In accordance with the present study, the high-viscosity conventional-GICs Group-I (Fuji IX GP) exhibited the minimum mean value of leakage in comparison with other tested materials; as seen in Figure 1 (a). AH Fil+ is an aesthetic durable GIC with high fluoride release and excellent biocompatibility. This study postulated that the dye penetration in Group-II (AH Fil$^+$) was slightly higher compared to Group-I (Fuji IX GP); as presented in Figure 1 (b).

GI Ceramic Reinforced Extra is a new generation of GIC for posterior restorations with easy handling, superb aesthetic and high wear resistance, which is formed by substituting the silver metal alloy with ceramic particles. A high significant degree of microleakage was seen in the filled cavities of Group-III (GI Ceramic Reinforced Extra) after 24 hr of soaking in blue dye; as shown in Figure 1 (c). Statistically, it was found that no significant differences between GI Ceramic Reinforced Extra and other two tested materials ($p > 0.05$); as given in Tables 2-3.

Well known that the setting reaction of GICs is quite complex, as its based on the acid-base reaction. This reaction occurs when the calcium fluoro-alumino-silicate glasses (acid-degradable glasses) and the aqueous solution of poly-acrylic acid are mixed together to form the final set cement [30]. Nicholson [31] stated that all techniques used for studying the setting reaction of GICs emphasised that the reaction of these water-based cements includes neutralisation of acid by basic glass, via formation of metal poly-acrylates (calcium and aluminium acrylates). Once ionomer cements are applied to the tooth surfaces, poly-acrylic acid forms complexes with calcium ions, resulting in formation of chemical bond between the substrate and the cement [32].

It is believed that the conventional, high-viscosity GIC is considered as a promising restorative material, which holds an inferior place in the application of posterior occlusal fillings, and in the minimally invasive dentistry, especially for atraumatic restorative treatment. Different additives (modifiers) have been incorporated into conventional-GIC to improve their physico-mechanical properties. These additives have changed the original composition and ratio between the elements of ionomer glasses; for example, the fluoride, calcium content and the ratio of aluminium to silica; thus the performance of the materials in terms of the marginal integrity will be changed as well [33-34].

It is thought that the GIC reinforcement with inorganic ceramic particles has been complicated the behaviour/phenomenon of GIC reaction. This behaviour/phenomenon could be analysed in accord with interfering of these additives with the crosslinking process of the cement at the short-term stages of the reaction. This may cause a definite disruption in the bond formation between the calcium ions (Ca^{2+}) of hydroxyapatite and carboxylic group (−COOH) of poly-acrylic acid; thereby the ions exchange (adhesion) process at the interfaces could be interrupted. This finding goes in an excellent agreement with the showing evidence in the previous work for reinforced restorative materials [35].

According to Hussin *et al.* study, it was found that the highest marginal leakage scores in the newly modified hybrid (GIC-nanoZrO2-SiO2-HA) material compared to Fuji IX [36]. This finding coincides with the results observed in this study. While, in another comparative microleakage studies performed by Diwanji *et al.* [37] and Singla *et al.* [38] using 1% aqueous solution of Acridine dye and 1% methylene blue dye respectively, the maximum leakage was detected with Fuji IX restorations. Furthermore, the differences in the experimental conditions may contribute to the results of these researches.

Another possible explanation may be owing to the variation in the filler particles size (ceramic particles), their distribution and in the inter-connected porosity in Ceramic Reinforced GIC matrix, which may prevent the proper adaptation of this material to the substrate. This is most likely to be attributed to the gap formation at the tooth-restoration interfaces. Usually, the particle size of ionomer glasses has a crucial impact on the properties of GICs including; setting time, compressive strength and it thoughts that might affect the adhesion/cohesion process between the components of GICs [39-40]. It is possible that the reduction in particle size of ionomer glasses is needed in order to accelerate the crosslinking mechanism and further to improve the microstructure and the mechanical properties of the ionomer cements [40].

In the current study, the samples were subjected to thermo-cycling process by soaking them in cold and hot bath within the range of 5-55 ºC with dwell-time of 15 sec in order to simulate the oral environment. This process could provide thermal stress due to the differences in temperature of cold bath, room temperature (during transferring time) and hot bath respectively. In other words, this causes a period of expansion and contraction inside the tested material. It is probably that the variances in the temperature values will stressed the tested materials, causing an increase in the leakage incidence [41].

A crucial problem for the marginal leakage assessment is the availability of human teeth. The used teeth should have some standard characteristics like being free of caries and cracks, but it is not always possible to provide these features every time. Therefore, teeth of various mammals like cows and dogs are used as an alternative substrate due to the similarity to those of human teeth [42]. A research carried out by Yavuz *et al.* concluded that the primary teeth of the dog and/or bovine exhibit similar characteristics of leakage that obtained when human teeth was used [43].

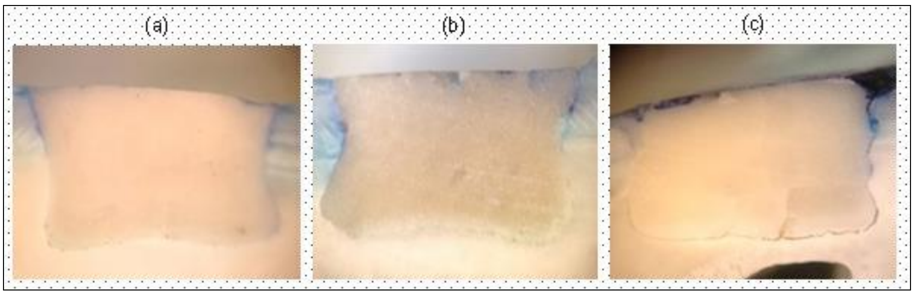

Fig 1: Marginal leakage in (a) Group-I (Fuji IX GP), (b) Group-II (AH Fil$^+$), and (c) Group-III (GI Ceramic Reinforced Extra)

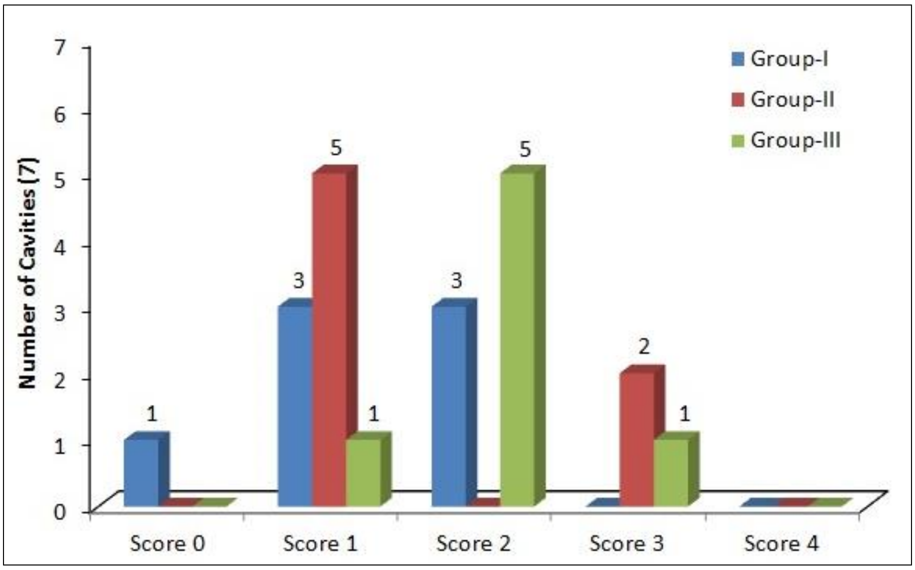

Fig 2: Corresponding marginal leakage scores in each group; Group-I (Fuji IX GP), Group-II (AH Fil+), Group-III (GI Ceramic Reinforced Extra)

Table 1: Details of tested materials for marginal leakage study

Materials	Manufactures	Delivery	Ratio	Mixing Method
Fuji IX GP	GC, Japan	P/L	1:1	Hand-mix
AH Fil+	AHC, UK	P/L	1:1	Hand-mix
GI Ceramic Reinforced Extra	AHC, UK	P/L	2:1	Hand-mix

Table 2: Mean values of marginal leakage scores with their standard deviations (SD) and minimum-maximum (min-max) values for tested groups

Groups	Mean± SD	Min-Max
Fuji IX GP	1.29±0.75[a]	0.00-2.00
AH Fil+	1.57±0.97[a]	1.00-3.00
GI Ceramic Reinforced Extra	2.00±0.57[a]	1.00-3.00
P-value	0.213	

Different superscript letters represent the significant differences between the tested groups ($p < 0.05$)

Table 3: Paired comparison of marginal leakage between tested groups

GROUPS	*P*-value
Fuji IX GP vs AH Fil+	0.775***
Fuji IX GP vs GI Ceramic Reinforced Extra	0.072***
AH Fil+ vs GI Ceramic Reinforced Extra	0.217***

P-value* is highly significant; *P*-value** is significant; *P*-value*** is non-significant

Conclusion

Within the limitation of this *in-vitro* study, it would be concluded that Group-I (Fuji IX GP) presents a better marginal integrity in comparison to Group-II (AH Fil+) and Group-III (GI Ceramic Reinforced Extra). There was no significant superiority of any of tested materials over the others; thus all could be used in clinical applications. The longevity of restorative materials along with marginal adaptability should be clinically evaluated with further advanced techniques.

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Author's Contribution

Not available.

Conflict of Interest: Not available.

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