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In vitro wear and fracture toughness of an experimental light-cured glass–ionomer cement

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ABSTRACT

Objective. The objective of this study was to evaluate the *in vitro* wear and fracture toughness (FT) of an experimental resin-modified glass–ionomer cement (RMGIC) formulated with the newly synthesized 6-arm star-shape poly(acrylic acid) and Fuji II LC glass fillers and investigate the effects of several important formulation parameters on wear-resistance and FT of the cement.

Materials and Methods. The *in vitro* abrasive and attritional wear as well as FT of the newly developed RMGIC were evaluated. The resin composite P-60 and RMGIC Fuji II LC were used as controls. The effects of glycidyl methacrylate (GM)-grafting ratio, powder/liquid (P/L) ratio, polymer/water (P/W) ratio and aging in water were investigated. All the specimens were conditioned in distilled water at 37 °C for 1 day prior to testing, unless specified.

Results. The optimized experimental cement exhibited almost the same high initial wear-resistance to abrasion as P-60 and much higher than Fuji II LC. The experimental cement showed 1.4 times higher in resistance to attritional wear than Fuji II LC but 6 times lower than P-60. After 1-month aging, the cement can compete with P-60 in resistance to attritional wear by showing only 1.3 times more in wear depth. The experimental cement also showed a significantly higher FT value than Fuji II LC but a similar value to P-60.

Conclusions. It appears that this novel experimental cement may be potentially used for high wear and high stress-bearing site restorations such as Class I and II.

1. Introduction

Wear is a common phenomenon in restorative dentistry that occurs when two surfaces undergo sliding or slipping movements as a load is applied, especially in Class I and II restoration [1,2]. Wear resistance is one of the most challenging properties to all direct dental filling restoratives [2]. So far two major dental restoratives are being used for high wear and high stress-bearing sites such as Class I and II restorations [3]. One is traditional dental amalgam and the other is a contemporary resin composite. Due to concerns of potential corrosion in service, controversy mercury toxicity issues and non-tooth color, resin composites have nearly replaced dental amalgams for more than 20 years in most developed countries [2]. However, resin composites still have their own significant shortcomings such as relative complicated manipulation technique, non-adhesion to tooth, shrinkage, water absorption and relatively high thermal expansion coefficients

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[3,4]. Efforts have been made to find an alternative that can eliminate or reduce the disadvantages of both amalgams and resin composites [2,4]. Glass–ionomer cements (GICs) have been considered to be a leading candidate so far [5,6].

GICs have exhibited numerous unique properties that both resin composites and amalgams do not have [5–7]. These unique properties include direct adhesion to tooth and base metals due to capability of crosslinking with calcium ions in tooth or metal ions in base metals [8,9], anticariogenic properties due to release of fluoride [10], thermal compatibility with tooth enamel and dentin because of low thermal expansion coefficients similar to that of tooth [3], minimized microleakage at the tooth-enamel interface due to low shrinkage [3], and low cytotoxicity due to low content of monomers incorporated [11,12]. Despite numerous advantages of GICs, brittleness, low mechanical strength and poor wear resistance have restricted the current GICs for use mainly at certain low stress-bearing sites such as Class III and Class V cavities [5,7]. Much effort has been made to focus on improving mechanical strengths of GICs [5,13–20] but only a few on enhancing wear-resistance [21–23]. The examples in attempts to improve wear-resistance of GICs include the incorporation of silver or/and amalgam particles [21], addition of montmorillonite clay filler [22], and use of high viscous glass–ionomer formulation [23,24]. Incorporation of silver or amalgam particles did show some improvement but not significantly [21,25]. It was also found that due to the addition of silver or amalgam, the cements have significantly changed their color to be incompatible with natural tooth [25]. The addition of nontmorillonite clay filler did not improve the wear-resistance much [22]. High viscous GICs such as Fuji IX and Ketac–Molar were originally designed to improve both mechanical strength and wear-resistance, but their improvement in wear-resistance was limited [23]. Although these two cements do show a better wear-resistance than the other GICs, they failed in load-bearing areas [26] and are not durable as compared to resin composites [3,24].

To be clinically successful, dental restoratives, especially those posterior filling materials, must be wear-resistant. There exist several common wear phenomena including abrasion, attrition, adhesion, chemical degradation and fatigue [2]. Among them abrasion and attrition are the most common wear phenomena encountered during the chewing cycle [1,2]. Abrasion is caused by frictional surface interactions with toothbrush, toothpaste, food bolus and fluid components during chewing. This type of wear is considered an important mechanism of occlusal material loss with resin composites. Attrition is caused by direct contact of sharp roughness asperities of the antagonist, which should at least be about 50% harder than the wearing substrate for substantial wear to occur. Attrition may cause substantial changes in surface texture (roughness, smear layer, etc.) [2]. FT measures the ability of materials, especially relatively brittle materials, to resist crack initiation and propagation. FT is another important property in which GICs are often lower as compared to resin composites [27].

Recently, we have developed a novel star-shape glass–ionomer system [28,29]. This system has no monomer in it. Because of this unique nature, the system has demonstrated impressively higher mechanical strengths (compressive strength (CS) = 334.9 MPa, diametral tensile strength (DTS) = 39.5 MPa and flexural strength (FS) = 98.4 MPa) as compared to Fuji II LC (CS = 228.2 MPa, DTS = 21.2 MPa and FS = 44.2 MPa) [30]. These values were very close to those for resin composite P-60 (CS = 349.1 MPa, DTS = 43.9 MPa and 157.6 MPa, recently tested in our lab). Furthermore, the system has demonstrated much better biocompatibility than two commercially sound RMGICs, Fuji II LC and Vitremer [29]. The results indicate that there exists great potential for this experimental cement to be a successful alternative for resin composites if its wear-resistance and other properties are close to resin composites.

The objective of this study was to evaluate the *in vitro* wear and FT of an experimental RMGIC formulated with the newly synthesized 6-arm star-shape poly(acrylic acid) and Fuji II LC glass fillers and investigate the effects of several important formulation parameters on wear-resistance and FT of the cement.

2. Materials and methods

2.1. Materials

Dipentaerythritol, triethylamine (TEA), 2-bromoisobutyryl bromide (BIBB), CuBr, *N*,*N*,*N*′,*N*′,*N*″-pentamethyldiethylenetriamine (PMDETA), dl-camphoroquinone, 2-(dimethylamino)ethyl methacrylate, pyridine, tert-butyl acrylate (t-BA), glycidyl methacrylate (GM), hydrochloric acid (37%), diethyl ether, dioxane, *N*,*N*-dimethylformamide and tetrahydrofuran (THF) were used as received from VWR International Inc (Bristol, CT) without further purifications. Fuji II LC cement and Fuji II LC glass powders were used as received from GC America Inc (Alsip, IL). Filtek P-60 resin composite was used as received from 3 M ESPE (St. Paul, MN).

2.2. Synthesis of the GM-tethered 6-arm star-shape poly(acrylic acid)

The GM-tethered 6-arm star-shape poly(acrylic acid) was synthesized similarly to those procedures described in our previous publications [28,30]. Briefly, dipentaerythritol in THF was used to react with BIBB in the presence of TEA to form the 6-arm initiator. t-BA in dioxane was then polymerized with 0.5% synthesized 6-arm initiator in the presence of CuBr/PMDETA catalyst complex via atom transfer radical polymerization at 120 °C. The resultant 6-arm poly(t-BA) was hydrolyzed with hydrochloric acid and dialyzed against distilled water. The purified 6-arm poly(acrylic acid) with molecular weight (MW) of 15,000 Da was obtained via freeze-drying. The 6-arm poly(acrylic acid) in *N*,*N*-dimethylformamide was then tethered with GM in the presence of pyridine. The GM-tethered polymer was recovered by precipitation from diethyl ether, followed by drying in a vacuum oven at 23 °C. The overall synthesis scheme is shown in Fig. 1.

2.3. Sample preparation

The experimental cements were formulated with a two-component system (liquid and powder) [28]. The liquid was formulated with the GM-tethered polymer, water, 0.9%