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BONDING ABILITY AND MECHANICAL STRENGTH OF RECENTLY FORMULATED GLASS IONOMER CEMENTS

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ABSTRACT

This study was aimed to compare calcium aluminate glass ionomer cement (Ceramir, Doxa Dental AB) as a new formulation with conventional and resin modified glass ionomer cements (Riva SDI). A total number of 90 samples were used in this study. The samples were divided into 3 main groups according to type of materials (each group was 30 samples), they were then subdivided into two subgroups according to the test performed with 15 samples in each subgroup. They were tested for their compressive strength and shear bond strength. **Results:** Data analysis was performed using One way ANOVA followed by Tukey's pair-wise .P values ≤0.05 are considered to be statistically significant in all tests, it was found that resin modified glass ionomer cement recorded the highest statistically significant mean values of compressive strength and shear bond strength, while the lowest values were recorded for the conventional glass ionomer in compressive strength while ceramir recorded the lowest shear bond strength. **Conclusion:** Calcium aluminate modified glass ionomer cement recorded an intermediate compressive strength mean value between resin modified and conventional glass ionomer cements, it also recorded the lowest shear bond strength mean value compared to resin modified glass ionomer and conventional glass ionomer cement.

KEY WORD; Ceramir, Compressive strength, Shear bond strength

INTRODUCTION

Glass ionomer cements were first reported by Wilson and Kent in 1972) 1(and have since become widely used in clinical dentistry. They have many desirable properties, in particular the ability to form satisfactory adhesive bonds with enamel and dentin(2) ,and to release of fluoride in a sustained way over a prolonged periods of time3() , However glass ionomer cements have some limitations in their applications due to low early mechanical strength and short working time, glass ionomer cements have also shown moisture sensitivity especially during the initial stages of the setting reaction (4) .There have been recent modifications that replace part or most of the original formulations with alternative filler particles and/or matrix setting reaction (5) .

These modifications include different metal oxides and resinous formulation to improve the properties of glass ionomer cement. Within the last two to three decades, a new class of dental materials has emerged (6,7). This group of cements shares three characteristics, namely they contain comparably high levels of calcium, they display a pH in the alkaline range, and they are bioactive, namely these materials form surface apatite in the presence of physiological levels of inorganic phosphate in a simulated body fluid (SBF) (8). These materials have evolved from clinical indications in which their initial low strength properties were adequate (9). Although the unique biocompatibility and biological regenerative properties have been well documented in the literature (10). To our knowledge little data available about the bond strength and mechanical property of such materials, therefore it will be of value to investigate the compressive strength and bond strength of such newly developed calcium aluminate modified glass ionomer cement

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MATERIALS AND METHODS

Three different types of glass ionomer based materials were used during this study, Conventional glass ionomer (Riva SDI), Resin modified glass ionomer (Riva SDI) and Calcium aluminate modified glass ionomer (Ceramir, Doxa Dental AB) cements.

A total number of 90 samples were used in this study. The samples were divided into 3 main groups according to type of materials (each group was 30 samples), they were then subdivided into two subgroups according to the test performed with 15 samples in each subgroup.

Compressive strength test:

Mould construction: a special designed Teflon mold was prepared to form cylindrical samples with dimensions of 3 mm in diameter and 6 mm in height. These dimensions were determined according to International Standards Organization (ISO) No. 9917 (2007) [11].

Sample preparation: The foil pack of the cement capsule was removed. The plunger was pushed firmly on the surface, until it was flushed with the body of the capsule. Then the capsule was placed into the amalgamator. The capsule was triturated for 10 seconds. The capsule was removed from amalgamator and placed into the Riva applicator. The mixed cement was condensed in the Teflon mold which was placed on glass plate. Samples were covered with celluloid strip and pressed with another glass plate. The samples were removed from the mold after setting and stored in distilled water for 24 hours prior to testing. Universal mechanical testing machine was used to measure the compressive strength of all samples. **Compressive strength testing:** the samples were loaded on the Lloyd mechanical testing machine at cross head speed of 1 mm/min. The samples were placed with flat end vertically between the two metal Plates the load was applied until the sample was crushed and the peak force required to fracture each samples was recorded in Newton from stress strain curve. The compressive strength was calculated in (MPa) using the following equation: $CS = 4P/\pi d^2$

Where (CS) is the compressive strength (MPa), (P) is the load at the fracture point (N), (d) is the diameter (mm) of the sample and (π) is a constant = 3.14.

Shear bond strength test.

Samples preparation: Forty-five freshly extracted human permanent mandibular molars with no crack, decay or structure deformities were collected and stored in normal saline. After removing tissue tags the teeth were cleaned with pumice. The roots were embedded in self-cure acrylic resin block made by especially designated poly vinyl chloride (PVC) mould (1.5 cm length x 2cm diameter). Flat dentine surface was obtained after grinding the occlusal surface of teeth. In such way the flat dentine surface was flushed with acrylic resin. For resin groups only, the flat dentine surface was treated by conditioner (liquid of conventional type for 10 second) according to manufacture recommendations. After conditioning, the samples were washed by water and dried by oil free air without desiccating tooth surface. Cylindrical samples of different glass ionomer types used in this study were constructed over the flat dentine surface using special Teflon mould (5mm length x 2mm diameter) [12] and stored in distilled water for 24hour after setting. **Shear bond strength testing:** a circular interface shear test was designed to evaluate the bond strength. All samples were individually and horizontally mounted on a computer controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, USA) with a loadcell of 5 kN and data were recorded using computer software (Bluehill Lite; Instron Instruments) Samples were secured to the lower fixed compartment of testing machine by tightening screws. Shearing test was

done by compressive mode of load applied at tooth-filling interface using a mono-beveled chisel shaped metallic rod attached to the upper movable compartment of testing machine traveling at cross-head speed of 0.5 mm/mi. The load required to debonding was recorded in Newton.

Shear bond strength calculation; The load at failure was divided by bonding area to express the bond strength in MPa: $\tau = P/ \pi r^2$ Where; τ =shear bond strength (MPa, P =load at failure (N), π =3.14 and r =radius of disc (mm)

Statistical analysis; data analysis was performed in several steps. Initially, descriptive statistics for numerical data. One-way ANOVA followed by Tukey's pair-wise tests were done between groups in test results. Statistical analysis was performed using Graph-Pad Prism-4 statistics software for Windows. P values ≤0.05 are considered to be statistically significant in all tests.

RESULTS

Compressive strength test results:

Descriptive statistics for compressive strength test results measured in mega-Pascal (MPa) showing mean values and standard deviation, range (minimum and maximum) and 95% confidence intervals (lower and upper) for all experimental groups are summarized in table (1) and graphically drawn in figure (1). The highest mean ± SD values of diametral compression strength were recorded for RMGI group (209.599±4.78 MPa) with minimum value (204.8 MPa) and maximum value (217.53 MPa) followed by Ceramir group with mean ± SD values (52.068±9.16 MPa) with minimum value (45.49 MPa) and maximum value (67.79 MPa) meanwhile the lowest mean ± SD value was recorded for GIC group (47.375±5.21 MPa) with minimum value (40.79 MPa) and maximum value (53.96 MPa). The difference between all experimental groups was statistically significant as indicated by one-way ANOVA test (F=965.2, P=.0001<0.05). Pair-wise Tukey's post-hoc test showed no-significant difference between GIC and Ceramir as shown in in table (1) and figure (1).

TABLE 1: Comparison of compressive strength test results (Mean ±SD) values for all experimental groups

Variables		*Mean ±SD*	*ANOVA* *P value*
Experimental Groups	*GIC*	47.38^{B}±5.21	<.0001*
	RMGI	209.59^{A}±48	
	Ceramir	52.07^{B}±9.16	

Different letter indicating significant (p<0.05)

**; significant (p<0.05) ns; no-significant (p>0.05)*

Shear bond strength test results:

Descriptive statistics for shear bond strength test results measured in mega-Pascal (MPa) showing mean values and standard deviation, range (minimum and maximum) and 95% confidence intervals (lower and upper) for all experimental groups are summarized in table (2) and graphically drawn in figure (2). The highest mean ± SD values of bond strength were recorded for RMGI group (3.628±0.78 MPa) with minimum value (2.88 MPa) and maximum value (4.810 MPa) followed by GIC group with mean ± SD values (2.425±0.45 MPa) with minimum value (1.764 MPa) and maximum value (3.030 MPa) meanwhile the lowest mean ± SD value was recorded for Ceramir group (0.559±0.06 MPa) with minimum value (0.490 MPa) and maximum value (0.650 MPa). The difference between all experimental groups was statistically significant as indicated by one-way ANOVA followed by pair-wise Tukey's post-hoc tests (F=44.99, P=.0001<0.05) as shown in in table (2) and figure (2).

TABLE 2: Comparison of shear bond strength test results (Mean ±SD) values for all experimental groups

Variables		Mean ±SD	ANOVA
			P value
Experimental Groups	***GIC***	2.425^{B}±0.45	<.0001*
	RMGI	3.628^{A}±0.78	
	Ceramir	0.559^{C}±0.06	

Different letter indicating significant (p<0.05)

**; significant (p<0.05) ns; no-significant (p>0.05)*

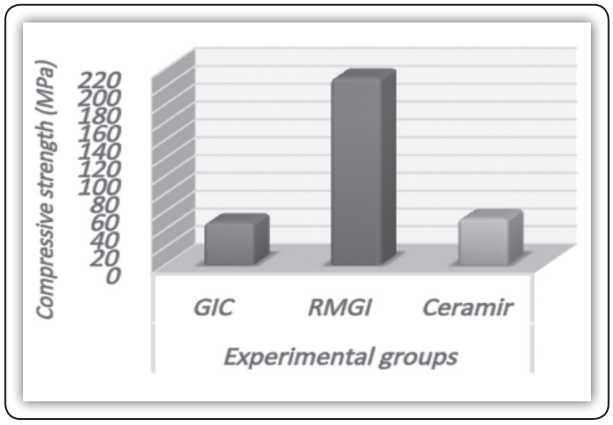

Fig. (1) Column chart of the mean values of compressive strength for all experimental groups

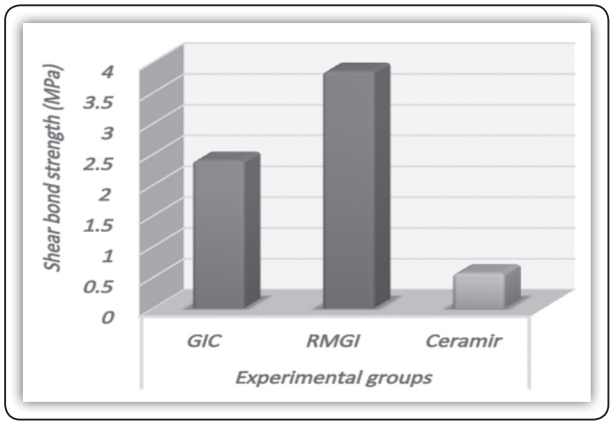

Fig. (2) Column chart of the mean values of shear bond strength for all experimental groups

DISCUSSION

This study was designed to evaluate some properties of recently developed calcium aluminate modified glass ionomer cement (Mechanical properties; compressive strength and adhesion properties; shear bond strength with dentine) compared to conventional glass ionomer cement and resin modified glass ionomer cement. These two common properties were tested because they affect the survivability of the restorative materials. Glass ionomer (GI) cements have many desirable properties, in particular the ability to form satisfactory adhesive bonds with enamel and dentin[2] , release of fluoride in a sustained way over a prolonged periods of time, adhesion to base metals due to capability of crosslinking with metal ions in base metals, thermal compatibility with tooth enamel and dentin because of low thermal expansion coefficients similar to that of tooth, minimized microleakage at the tooth enamel interface due to low shrinkage, low cytotoxicity due to low content of monomers incorporated, excellent compatibility with the pulp, porcelain like translucency which is derived from the glass and favorable bioactive properties[4] .

However, glass ionomer cements have some limitations in their applications due to low early mechanical strength and short working time, glass ionomer cements have also shown moisture sensitivity especially during the initial stages of the setting reaction, Insufficient wear-resistance, post cementation sensitivity, brittleness and inadequate surface properties[3]. No dental material today has ideal properties for any dental application. In order to overcome the poor mechanical properties of glass ionomers, several modifications have been introduced to the conventional GICs. The key modifications include the combination of glass ionomer cements with calcium aluminate to produce calcium aluminate glass ionomer cements (CERAMIR C&B) is a new dental luting agent intended for permanent cementation of crowns and bridges, gold

inlays and onlays, prefabricated metal and cast post and cores and all-zirconia or all-alumina crowns. The cement is a water-based hybrid composition comprising of calcium aluminate and glass ionomer components that is mixed with distilled water. The material has been demonstrated to be bioactive [13]. There are several features that strongly contribute to the biocompatibility profile of the material. These include the fact that after setting, the material is slightly acidic, pH ~4. After 1 h, the pH is already neutral and after 3-4 hrs. It reaches a basic pH of ~8.5. This means that the fully hardened material is basic and stays basic throughout its service. This basic pH is the most important prerequisite for the material to be bioactive, that is, creating apatite on its surface when in contact with phosphate-containing solutions. The apatite forms during hardening but its formation continues when the hardened material is in contact with phosphate solutions. The basic pH is also an important factor in the biocompatibility profile of the material [14]. Additionally, the material produces an excess of Ca^{2+} ions, which also contributes to its bioactivity. The incorporation of calcium aluminate fixes the GIC structure and hinders the ionomer glass from continuously leaking over time. Ceramir C&B has an initial fluoride release comparable to a glass ionomer, although the release tapers off over time. Unique properties such as apatite formation and remineralization develop quickly and continue to be active [14].

The compressive strength is an important property in evaluating restorative and luting materials, particularly in the process of mastication. This test is more suitable to compare brittle materials, which show relatively low result when subject to tension. To test compressive strength of a material; two axial sets of force are applied to toward each other, in order to approximate the molecular structure of the material. In this test, a compressive force is applied to a cylindrical specimen across its long axis by compression plates [15].

The adhesion of dental materials to dentin has been extensively investigated in the last decades in order to make it effective and durable, but due to dentin complexity this is an arduous procedure. Unlike enamel, dentin is a live, dynamic tissue that contains greater portion of water and organic material. It is connected to the pulp through the dentinal tubules, which extend from the pulp to the dentino-enamel junction. These tubules contain dentinal fluid that is responsible for the intrinsic humidity of this structure [16]. Different mechanical tests have been proposed to assess the bonding performance of restorative materials. Bond strength test methods include; macro and micro test designs according to interfacial bonding area in tension shear and push out. Shear bond strength testing has been widely used to evaluate the bonding ability of adhesive materials to dental structure rather than other bond strength test methods due to its simplicity, easiness, cost efficient and because most intra-oral failure occurs through shear forces [17]. The data in table (1) and figure (1) revealed that the resin modified glass ionomer cement recorded statistically significant higher compressive strength followed by calcium aluminate modified glass ionomer cement and the lowest value of test are conventional glass ionomer. In this study the high compressive strength of the resin type of glass ionomer was due to integrated interfaces between glass particles and polymer matrix.

This result is in agreement with some investigators determined the effect of water storage on flexural strength (FS) and compressive strength (CS) of luting cements from different material classes. The materials examined were two glass ionomer cements three resin-modified glass ionomer cements and reported that that RM-GIC has a compressive strength higher than that of conventional GIC [18-20] .

While the result was in disagreement with some investigators who compared compressive strength (CS) of conventional glass ionomer with resin mod-

ified glass ionomer and reported that conventional glass ionomer cement exhibited greater compressive strength than the resin modified glass-ionomer cements. Similar results have previously been reported[21-33] . This result is related to difference in materials used, experimental design, samples size or samples conditioning methods. In calcium aluminate modified glass ionomer cement the compressive strength is higher than conventional type this increase was due to aluminum ions concentration in calcium aluminate rather than conventional type. This was in agreement with some investigators who reported that Al^{3+} is a major contributor to improve strength because it is believed to form three dimensional crosslinks but not Ca^{2+} or Sr^{2+}, which makes huge strength difference between glass-ionomer cement and other cements [21,22] .

Mitra and his co-workers suggested that the leaching of Al^{3+} from the glass particles is an important factor in conferring strength to the cements, although, the presence of Al_2O_3 in the reacted glass particles may well also contribute to the mechanical performance of the calcium aluminate GICs [21] .This results is in contradictory to investigators who determined physical and mechanical laboratory properties of calcium aluminate modified glass ionomer cement regarding compressive strength and other mechanical properties and reported that the calcium aluminate modified glass-ionomer cement (CC&B) showed significantly higher compressive strength than the resin-modified glass ionomer (RMGI) cements [7] .This is due to difference in materials used, experimental design, samples size or samples conditioning methods. The data in table (2) and figure (2) revealed that the resin modified glass ionomer cement recorded statistically the highest shear bond strength followed by conventional glass ionomer cement and lowest value of test are calcium aluminate glass ionomer.

Good bonding by resin-modified glass-ionomers is partly a function of the fact that they contain a polymeric acid such as poly(acrylic acid), which is capable of interacting strongly with the mineral phase of the tooth[24] .In addition, they contain HEMA, a substance that is also currently used as a component of dentine bonding agents[16] .The effect of this combination is not known for certain, but is likely to result in high bond strengths and durable bonding to the tooth surface. Unlike conventional glass-ionomers, there is evidence that resin-modified glass-ionomers bond more strongly to the dentine than to the enamel, and this may be a function of their HEMA content[25] .The bonding of resin-modified glass-ionomer cements is associated with the formation of a gel phase at the interface between the material and the tooth surface. This phase seems to originate from the acid–base part of the formulation, as it consists substantially of calcium polyacrylate, a substance that forms as the cement sets. However, the gel phase is more substantial in these materials than in conventional glass-ionomers, so that its occurrence owes something to the overall composition of resin-modified glass-ionomers.[26] This is agreement with some investigators who compared shear bond strength of two commercially available resin-modified glass ionomer cements to bovine dentine, The explanations for this include the possibility of the formation of a hybrid like layer and the development of the better wetting of the dentin by the HEMA contained in the RM-GIC [27-33] .

The better performance of resin modified glass ionomer cement could be due to their expected dual mechanism of adhesion. For conventional glass ionomer the underlying mechanism of adhesion is thought to be based on a dynamic ion exchange process, in which the polyalkenonic acid softens and infiltrates the hydroxyapatite structure. There it is hypothesized to displace calcium and phosphate ions out of the substrate and to form an intermediate adsorption layer of calcium and aluminum phosphates and polyacrylates at the glass ionomer hydroxyapatite interface. In case of resin modified glass

ionomer cement the adhesion is probably through a combination of later mechanism and micro mechanical bonding mechanism [34-36] . The lower shear bond strength of calcium aluminate modified glass ionomer cement might be due to presence of fewer amounts of free carboxylic groups that can chemically bond with dentine. The adhesion between glass ionomer cement and tooth structure depend on formation of hydrogen bonds originating from the free carboxyl groups in the cement interacting with tightly bound water on the surface of the mineral phase of the tooth . These hydrogen bonds seem to be gradually replaced by true ionic bonds formed from cations in the tooth interacting with polymeric anions in the cement. This finding is in agreement with some studies that showed that an ion-exchange layer was slowly formed between the tooth and the cement [37- 40].

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