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Study of the Mechanical Properties of the Novel Zirconia-reinforced Glass Ionomer Cement

[1]Vemina P Chalissery, [2]Nikhil Marwah, [3]Mohammed Almuhaiza, [4]Abdulaziz M AlZailai, [5]Elna P Chalisserry [6]Shilpa H Bhandi, [7]Sukumaran Anil

ABSTRACT

Objectives: The purpose of this *in vitro* study is to compare the compressive strength (CS) and diametral tensile strength (DTS) of the zirconia-reinforced restorative material (Zirconomer®) with conventional glass ionomers (Fuji 1X) and amalgam.

Materials and methods: Specimens (n = 120) were fabricated from silver amalgam, reinforced glass ionomer cement (GIC) (glass ionomer, Fuji 1X GC Corp.), and zirconia-reinforced glass ionomer (Zirconomer, Shofu Inc.) for testing the CS and DTS. The results were analyzed using analysis of variance, followed by a Tukey *post hoc* test.

Results: Both CS and DTS were found to be significantly higher for the zirconia-reinforced GIC and silver amalgam compared with GIC ($p < 0.001$).

Conclusion: A newer class of restorative material like Zirconomer helps to overcome the potential hazard of mercury, but retains the strength and durability of amalgam as well as the sustained high-fluoride release of GICs. Furthermore, long-term studies are required to confirm its use as an alternative to the currently available posterior restorative material.

[1,2]Department of Pedodontics and Preventive Dentistry Mahatma Gandhi Dental College and Hospital, Jaipur Rajasthan, India

[3]Department of Restorative Dental Sciences, College of Dentistry, Prince Sattam Bin Abdulaziz University, Al-Kharj Kingdom of Saudi Arabia

[4]Department of Restorative Dentistry, Jazan Dental Center Jazan, Kingdom of Saudi Arabia

[5]Department of Maxillofacial Surgery and Diagnostic Sciences College of Dentistry, Jazan University, Jazan, Kingdom of Saudi Arabia

[6]Department of Restorative Dentistry, College of Dentistry Jazan University, Jazan, Kingdom of Saudi Arabia

[7]Department of Preventive Dental Sciences, College of Dentistry, Jazan University, Jazan, Kingdom of Saudi Arabia

Corresponding Author: Vemina P Chalissery, Postgraduate Student, Department of Pedodontics and Preventive Dentistry Mahatma Gandhi Dental College and Hospital, Jaipur Rajasthan, India, e-mail: Ksucod@gmail.com

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INTRODUCTION

The longevity of a dental restoration is essentially dependent on various factors that include properties of the dental material used, age of the patient, and rate of progression of caries in the restored tooth.[1] In the oral cavity, restorations undergo stress from masticatory forces producing different reactions that lead to deformation, which can ultimately compromise their durability over time.[2] This is limited if the strength of restorative materials is close to the strength of the tooth structure.[3] Thus, the quest for an ideal restorative material with optimum physical properties and durability exists.

Since the 1890s, amalgam – a metallic restorative material obtained by combining mercury and mixture of silver, tin, and copper alloy[4] – was widely chosen for such restorations by dental practitioners because of its high compressive strength (CS) (380–540 MPa) and tensile strength (57 MPa), durability, longevity, and marginal integrity of the material; moreover, there was lack of availability and development in the field of restorative materials. However, due to increase in demand of esthetics, its lack of adhesion to tooth surface, and the potential hazard of mercury toxicity considered by Food and Drug Administration (FDA),[4] the pursuit for alternative materials fulfilling these shortcomings began.

Glass ionomer (GI) cements were introduced by Wilson and Kent in 1972. Since then, several modifications have been introduced with the purpose of enhancing their mechanical properties.[5] The introduction of resin-modified GIs with superior mechanical strength was used in the posterior resorations.[6] The newer generation of GI retained the most desirable qualities of conventional versions, namely fluoride release, ion exchange adhesion to conditioned enamel and dentin, and low interfacial shrinkage stress.[7]

Recently, zirconia-reinforced GI (Zirconomer, Shofu Inc., Japan), a novel material, was introduced that could overcome the drawbacks of previously used tooth-colored restorative materials. It contains zirconium oxide, glass powder, tartaric acid (1–10%), polyacrylic acid (20–50%), and deionized water as its liquid. Zirconium oxide, the main powder component of Zirconomer, results from Baddeleyite (ZrO_2) that contains high levels of zirconia ranging from 96.5 to 98.5%.[8] In the early 1990s, zirconia was popularized into dentistry as endodontic posts,[9] later on as implant abutments[10] and hard framework cores for crowns and fixed partial dentures (FPDs).[11] The accessible zirconia powders have different grain sizes and different additives, such as yttrium oxide and alumina, which can be distributed homogeneously throughout the whole material or higher concentration at grain borders.[12] The grain-size variety affects the resulting porosity as well as the translucency of the material. The glass component of Zirconomer is subjected to controlled micronization, to acquire optimum particle size and characteristics.[8] The grain size has an effect on an exclusive characteristic of zirconia called transformation toughening, which gives it higher strength, toughness, high hardness, and corrosion resistance; thus, when it is homogeneously incorporated in the glass component, it further reinforces the material for lasting durability and high tolerance to occlusal load.[8] Hence, this biomaterial promises to show outstanding strength, durability, and sustained fluoride protection, thus combining and retaining the benefits of both popularly used restorative materials amalgam and conventional GI.

In light of the concerns associated with the strength of the restorative materials and its physical properties, which play a vital role in durability and resistance of the restoration to fracture due to occlusal load, the aim of this study is to compare the CS and diametrical tensile strength (DTS) of conventionally used amalgam (DPI alloy and mercury, Fine grain, Mumbai, India) and GI cements (Fuji IX GC Corp., Japan) with innovative restorative material, that is, zirconia-reinforced GI (Zirconomer, Shofu Inc., Japan).

MATERIALS AND METHODS

Samples

A total of 120 specimens (n = 120) were prepared with the three materials (Zirconomer, GI, and silver amalgam) used for the study (Table 1). A total of 60 specimens were used for testing CS and the remaining 60 were used for the DTS testing. The dimensions of these specimens were in accordance with the American Dental Association (ADA) specifications. They were prepared using molds with standard dimensions for the CS and DTS tests. All the three materials used were mixed and prepared according to the manufacturer's direction. Compressive strength (MPa) is calculated using the formula: $CS = 4P/\pi D^2$. The maximum load applied to fracture the specimens is recorded and the DTS, T (MPa), is calculated using the formula: $T = 2P/\pi DL$, where P is the maximum load applied (N), D is the measured mean diameter of the sample (mm), and L is the measured length of the sample (mm).

Table 1: The restorative materials tested in this study

Material	*Manufacturers*
Silver amalgam DPI Alloy and Mercury	Fine grain, Mumbai, India
Fuji 1X GIC	GC Corp., Japan
Zirconomer (zirconia-reinforced GI)	Shofu Inc., Japan

The mixed materials were slowly inserted, before it sets into preformed Teflon-coated cylindrical molds, making sure that no air bubbles were formed. According to ADA specifications, samples were prepared at room temperature of 23 ± 2°C, with a relative air humidity of 50 ± 10%. The material was then filled to excess in the molds, and plates were placed above it, followed by slight application of pressure for 15 to 20 seconds. The excess cement that extruded was removed. The test specimens were subjected to deionized water bath at 37 ± 1°C to equilibrate before testing.

Compressive Strength Testing

Compressive strengths were determined by using a method similar to that described by ADA.[13] Samples of each restorative material were prepared, and the powder/liquid ratio was determined according to manufacturer's directions for each material. To evaluate CS, a cylindrical mold of dimensions 6.0 mm diameter × 12.0 mm height was prepared. This test was carried out using the Instron universal testing machine that has a crosshead speed of 1.0 mm/minute (Fig. 1). Each sample was placed with the flat ends between the platens of the apparatus so that the load will be applied in the long axis of the specimens. The maximum load applied to fracture the specimens was recorded and the CS, C (MPa), was calculated using the formula $C = 4P/\pi D^2$, where P is the maximum applied load (N) and D is the measured diameter of the sample (mm).

Diametral Tensile Strength Testing

Samples of dimension 6.0 mm diameter × 3.0 mm height were used. Diametrical tensile strength of the sample

Fig. 1: The Instron machine used for testing. Note the specimen in place for testing the CS

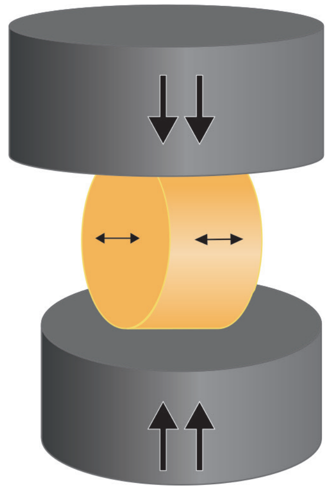


Fig. 2: Schematic illustration showing the mounting of sample to test DTS

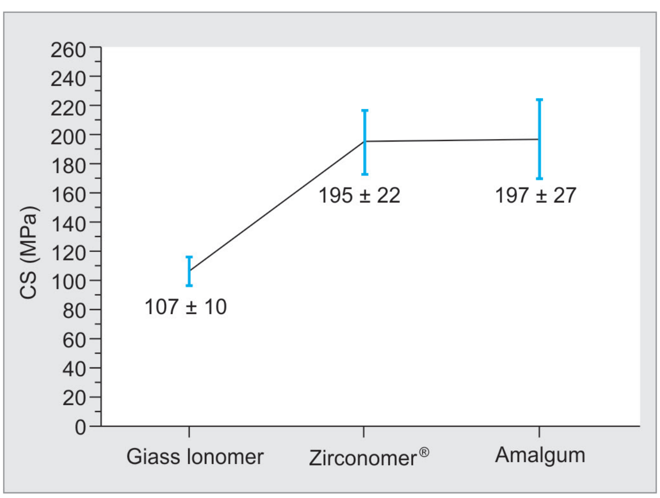
was investigated through a diametrical compressive test, and was determined using the Instron universal testing machine at a crosshead speed of 1.0 mm/minute. Samples were placed with the flat ends perpendicular to the platens of the apparatus so that the load was applied to the diameter of the specimens (Fig. 2). The maximum load applied to fracture the specimens was recorded and the DTS, T (MPa), was calculated using the formula: $T = 2P/\pi DL$, where P is the maximum load applied (N), D is the measured mean diameter of the sample (mm), and L is the measured length of the sample (mm).

Statistical Analysis

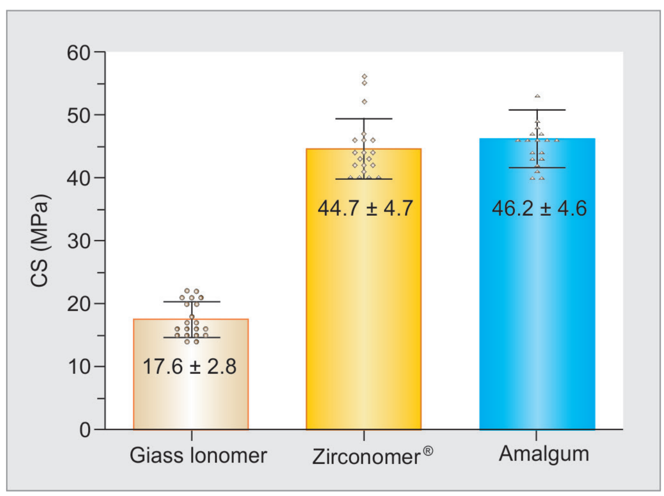
Statistical analyses of the CS and DTS testing were performed and the mean value with its standard deviation was calculated for each core material. Analysis of variance (ANOVA) was computed to determine whether statistically significant differences ($p < 0.05$) existed among core materials. Tukey's honest least significant difference multiple range test was used to determine which core materials were statistically different from one another ($p < 0.05$).

RESULTS

The CS of GI, Zirconomer, and amalgam was 107±10, 195±22, and 197±27 MPa respectively (Graph 1). The amalgam had the highest strength. The GI had a CS significantly lower compared with Zirconomer and amalgam ($p < 0.001$). Similarly, the DTS of the three materials is depicted in Graph 2. The DTS also showed



Graph 1: The compressive strength of the three materials tested



Graph 2: The diametral tensile strength (MPa) of the materials tested

similar pattern with 17.6±2.8 MPa for GI, which was significantly lower compared with Zirconomer (44.7±4.7) and amalgam (46.2±4.6). Even though amalgam expressed slightly higher values to Zirconomer, it was not significant.

DISCUSSION

Though amalgam has many drawbacks, such as postoperative tooth sensitivity, susceptibility to fracture of the restored teeth, microleakage, and high incidence of development of secondary caries, it has been used for more than a century as a successful restorative material. Many tooth-colored materials have evolved to replace amalgam in the recent past.[14,15] The popularity of resin-based composite restoration has increased because of its excellent esthetic and other favorable characteristics. However, failure is also seen in composite restoration in posterior dentition as excessive wear, polymerization shrinkage, open inter proximal contacts, tooth sensitivity, secondary caries, irreversible pulpitis, and restoration fracture.[16,17]

The unique properties of glass ionomer cement (GIC), such as adhesion to moist teeth, anticarcinogenic character, lack of exothermic polymerization, excellent adhesion to dentin, close thermal expansion to tooth, satisfactory biocompatibility, make it an important material in dental applications.[18] One of the major drawbacks is its weak mechanical properties like brittleness, low strength, and toughness.[19] Hence GICs were mostly used for the restoration of anterior teeth and in areas without any load due to their poor mechanical strength.[20] Several strategies are followed to enhance the mechanical properties, such as addition of zirconia, hydroxyapatite, N-vinyl pyrrolidone, fluoroapatite, and HA/ZrO_2 is a well-known method to enhance the mechanical properties of GIC.[21]

Zirconia, a high-strength ceramic, was introduced for dental use as a core material in conventional and resin-bonded FPDs and crowns.[22] Zirconia is highly rated in terms of esthetics and has several other advantages, including biocompatibility as it is metal-free and has a low degree of bacterial adhesion, high flexural strength, and acceptable optical properties, such as adaptation to the basic shades.[23,24] Zirconomer® (White Amalgam) is developed to exhibit the strength, i.e., consistent with amalgam, through a rigorous manufacturing technique. The glass component of this high-strength GI undergoes finely controlled micronization to achieve optimum particle size and characteristics. The homogeneous incorporation of zirconia particles in the glass component further reinforces the material for lasting durability and high tolerance to occlusal load. The polyalkenoic acid and the glass components have been specially processed to impart superior mechanical and handling qualities to this high-strength GI.[25] In the present study, we tested the mechanical properties of GI, Zirconomer®, and amalgam alloy in order to compare the properties, such as CS and DTS. Both CS and DTS were found to be higher for amalgam and zirconia-reinforced GI.

The addition of zirconia as filler particle in the glass component of Zirconomer® improved the mechanical properties of the restoration by reinforcing structural integrity of the restoration and can be used in load bearing areas, such as posterior restorations. The combination of outstanding strength, durability, and sustained fluoride protection deemed with chemical bonding makes it ideal for permanent posterior restorations in patients with high caries incidence as well as in cases where strong structural cores and bases are required. However, further *in vivo* studies are mandatory to substantiate our preliminary observations.

CONCLUSION

Despite the brilliant properties of GIC, its weak mechanical property poses an obstacle for its use as a posterior restorative material. The addition of zirconia has improved the mechanical properties compared with amalgam. Hence, it can be concluded that the zirconia-reinforced GI can be used as a posterior restorative material in load-bearing areas. Further *in vivo* studies are mandatory to prove its performance.

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