Original Article

# Evaluation of compressive and diametral tensile strength of novel bioactive material with conventional glass ionomer cement and silver amalgam: An *in vitro* study

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## Abstract

**Aim:** The aim of this study was to compare the compressive and tensile strength of two different brands of conventional glass ionomer cement (GIC), with new zirconia-reinforced GIC and silver amalgam.

**Materials and Methodology:** Eighty specimens with 20 samples in each group were prepared (Group 1-Fuji IX GIC, Group 2-FX-II Shofu GIC, Group 3-Amalgam, and Group 4-Zirconia-reinforced glass ionomer [Zirconomer]) for compressive strength (CS) using cylinder molds with dimensions 6.0 mm diameter × 12.0 mm height. Eighty specimens using cylinder molds with dimensions 6.0 mm diameter × 3.0 mm height were prepared for testing diametral tensile strength (DTS). CS test was carried out using Micro Universal Testing Machine (Mecmesin, PPT Group, UK) having a crosshead speed of 1.0 mm/min. DTS was determined using Instron universal testing machine at a crosshead speed of 1.0 mm/min. The data were submitted to two-way analysis of varianceand post hoc Tukey tests (alpha = 0.05). The mean CS value was more for Group III (256.2), followed by Group IV (181.2 Megapascals [MPa]), Group II (129.8 MPa), and the least was Group I (117.9 MPa).

**Result:** The mean DTS value was high in Group III (73.7 MPa), followed by Group IV (58.0 MPa), Group II (36.0 MPa), and the least was seen in Group I (23.2 MPa).

**Conclusion:** It can be concluded that although Zirconomer has mechanical properties greater than that of unmodified GICs, additional studies are essential to evaluate its long-time ability.

**Keywords:** Compressive strength; conventional glass ionomer cement; diametral tensile strength; silver amalgam; zirconia-modified glass ionomer

## INTRODUCTION

Posterior restorations constitute more than 70% of work in restorative dentistry and they are required to withstand different dynamic forces of compression and tension. Posterior restorative materials have been constantly evolving across various materials, from mechanically retained silver amalgam to current types of bonded restorative materials.

The wide use of dental amalgam as a direct posterior restorative filling material among general dental practitioners can be attributed to its strength, durability, wear resistance, cost-effectiveness, ease of manipulation, and long-term clinical performance.[1]

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It is known that the composition, particle shape, and size of amalgam alloys could all affect the manipulation, phase contents, and properties of amalgam. Crowell and Phillips mentioned that smaller particle sizes resulted in increased compressive strength (CS) of amalgam. The differences in composition and particle configuration among amalgams could also affect the grain size, CS, and handling characteristics of amalgam.[2,3] However, potential mercury toxicity and environmental hazards are cause for concern in amalgam among clinicians and the public, apart from its poor esthetic appearance.[1]

To overcome the limitations of silver amalgam, glass ionomer cement (GIC) was introduced in the early 1970s (Wilson and Kent, 1972). Glass ionomers possess certain properties such as low coefficient of thermal expansion which are similar to that of dentine. Chemical bonding to both enamel and dentin along with the release of fluoride ions into adjacent tooth structures made them more beneficial as restoratives.[4-6]

The major disadvantage of conventional glass ionomers as posterior restoratives are their poor mechanical properties of CS, three-point flexure strength, biaxial flexure strength, flexural modulus, wear resistance, and fracture toughness when compared with dental amalgam.[7] Attempts were made to improve cement strength by the addition of other materials such as resin or metal elements and to overcome the above mentioned demerits. The addition of silver alloy powder to glass ionomer powder was proposed to provide radio-opacity and increase strength. A variation of this proposed material was marketed as Miracle Mix in 1983. Another reinforced cement was Ketac Silver (ESPE), where silver particles were sintered to the glass to form cermet cement. One common characteristic of all metal reinforced cement is that they are not tooth colored and color ranges from light to dark gray.[4]

The early work of Kent and Wilson has been continued by Brune and Smith, who found mean particle sizing (based on sieve techniques) had little effect on CS. It is commonly known that GIC has larger mean particle sizes than other restorative materials, which is recognized as a contributing factor to the relative weakness of the material.[7]

The conventional glass ionomers lack in desirable mechanical strength and, therefore, do not meet the requirements to be used in Class I and Class II clinical situations.[8,9] Baig *et al*. identified tensile stress as a valid strength testing methodology as the specimens failed under tensile stresses which contraindicate their use in such indications.[10]

Recently, a zirconia-modified GIC, Zirconomer named as white amalgam with the inclusion of zirconia as fillers to the glass components, has been launched.[11] The manufacturer claims that zirconia reinforces the structural integrity of the restoration and imparts superior mechanical properties in posterior load-bearing areas as an alternative to the conventional choice of amalgam. The combination of improved strength, durability, and sustained fluoride protection deems it ideal for permanent posterior restoration in patients with high caries incidence as well as cases where strong structural cores and bases are required. It is ideal for Class I and II cavities and core build-up under indirect restoration.

The abovementioned claims have led to the opinion that the zirconia-reinforced glass ionomer can meet the functional requirements as an alternative to silver amalgam restorations in load-bearing situations, hence this study was done to compare the compressive and tensile strength of four posterior restoratives-two brands of conventional GICs and silver amalgam, with the zirconia-reinforced glass ionomer (Zirconomer).

## MATERIALS AND METHODS

### Sample preparation

The cements were manipulated according to the manufacturer's instructions for the preparation of test specimens and the mixed materials were placed into cylindrical molds. The molds were filled to excess and plates were placed above it, followed by a slight application of pressure. The excess cement which was extruded was removed. The test specimens were placed in a water bath for 24 h at 37°C ± 1°C to equilibrate before testing. Eighty specimens were divided into four groups each of 20 specimens ($n = 20$).

The four experimental groups are as follows:

1. Group I - Restorative GIC,(Fuji 1X, GC Corp, Japan) ($n = 20$)
2. Group II - Restorative GIC (FX-II, Shofu Inc. Japan) ($n = 20$)
3. Group III - Silver amalgam alloy (DPI Alloy and Mercury, Fine grain, Mumbai, India) ($n = 20$)
4. Group IV – Zirconia-reinforced glass ionomer (Zirconomer, Shofu Inc. Japan) ($n = 20$).

### Compressive strength testing

Eighty specimens ($n = 20$) for CS were prepared using cylinder molds with dimensions 6.0 mm diameter × 12.0 mm height for the CS test. All specimen materials were prepared according to the manufacturer's direction. CS testing was carried out using a Micro Universal Testing Machine (Mecmesin) having a crosshead speed of 1.0 mm/min. Samples were placed with the flat ends between the testing metal plates of the apparatus so that load was applied along the long axis of the specimens and the maximum load applied to fracture the specimens was recorded and CS in Megapascals (MPa) was calculated using the formula.

$C = 4P/\pi D2$

Where $P$ denotes the maximum applied load in Newtons ($N$), $D$ denotes the measured diameter of the sample in (mm).

### Diametral tensile strength testing

Eighty specimens ($n = 80$) for diametral tensile testing were prepared using cylinder molds with dimensions 6.0 mm diameter × 3.0 mm height for the DTS test. All specimen materials were prepared according to the manufacturer's directions. Diametral tensile strength (DTS) was determined using an Instron universal testing machine at a crosshead speed of 1.0 mm/min. Samples were going to be placed with the flat ends perpendicular to the platens of the apparatus so that the load was applied to the diameter of the specimens. The maximum load applied to fracture the specimens was recorded and DTS in 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), L is the measured length of the sample (mm).

## RESULTS

It was found that the mean CS value was more for Group III (256.2 MPa), followed by Group IV (181.2 MPa), Group II (129.8 MPa), and the least was Group I 117.9 MPa). The mean DTS value was high in Group III (73.7 MPa), followed by Group IV (58.0 MPa), Group II (36.0 MPa), and the least was seen in Group I (23.2 MPa) [Tables 1 and 2].

## DISCUSSION

An investigation of mechanical properties is an essential stage in the complex process of assessing the potential of a material for a specific dental application.[1]

The mechanical properties of an ideal posterior restorative material should be able to meet the functional requirements of the masticatory system with recommended wear and fracture resistance.

These limitations can be addressed by improving their mechanical properties by the addition of particulate metallic powders.[12]

Strength of the material is determined by the fracture stress within a restorative material. Two mechanical strength tests (Compressive and Diametral Tensile) were used in this study.[13,14]

Many brittle dental materials such as cement and amalgam have a tensile strength that is markedly lower than the CS. These materials fail by crack propagation on account of poor tensile strength rather than compressive loads. However, the indirect relation of CS to both tensile and shear modes of failure makes it a useful testing parameter.[15] Furthermore, CS can be considered to be a critical indicator of longevity and success of a posterior restoration as a higher CS is necessary to resist masticatory and parafunctional forces.[16-18]

This is the first study done to compare the mechanical properties of compressive and DTS of Zirconomer which is a zirconia-reinforced GIC with silver amalgam and unmodified glass ionomer restoratives (Fuji IX and Shofu FX II).

**Table 1: The compressive strength mean and standard deviation values of different restorative materials**

| Comparison of mean CS of different restorative materials using ANOVA followed by Bonferroni's ***post hoc*** analysis | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Restorative materials | *n* | Mean | SD | SE | 95% CI for mean | | Minimum | Maximum | *P* | Significant difference | *P* |
| | | | | | Lower | Upper | | | | | |
| Fuji GIC | 20 | 117.9 | 3.2 | 0.7 | 11.4 | 119.4 | 110.4 | 121.8 | <0.001* | 1 versus 2, 1 versus 3, 1 versus 4 | <0.001* |
| Shofu GIC | 20 | 129.8 | 3.7 | 0.8 | 128.1 | 131.6 | 123.2 | 136.9 | | 2 versus 3, 2 versus 4 | <0.001* |
| Amalgam | 20 | 256.2 | 8.5 | 1.9 | 252.2 | 260.1 | 235.9 | 270.7 | | 4 versus 3 | <0.001* |
| Zirconomer | 20 | 181.2 | 2.6 | 0.6 | 180.0 | 182.5 | 177.7 | 187.5 | | | |

*Statistically significant. SD: Standard deviation, SE: Standard error, GIC: Glass ionomer cement, CI: Confidence interval, ANOVA: Analysis of variance, CS: Compressive strength

**Table 2: The diametral tensile strength mean and standard deviation values of different restorative materials**

| Comparison of mean tensile strength of different restorative materials using ANOVA followed by Bonferroni's ***post hoc*** analysis | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Restorative materials | *n* | Mean | SD | SE | 95% CI for mean | | Minimum | Maximum | *P* | Significant difference | *P* |
| | | | | | Lower | Upper | | | | | |
| Fuji GIC | 20 | 23.2 | 2.2 | 0.5 | 22.2 | 24.2 | 19.4 | 27.9 | <0.001* | 1 versus 2, 1 versus 3, 1 versus 4 | <0.001* |
| Shofu GIC | 20 | 36.0 | 1.5 | 0.3 | 35.3 | 36.7 | 32.6 | 39.1 | | 2 versus 3, 2 versus 4 | <0.001* |
| Amalgam | 20 | 73.7 | 1.8 | 0.4 | 72.8 | 74.5 | 69.2 | 76.2 | | 4 versus 3 | <0.001* |
| Zirconomer | 20 | 58.0 | 1.7 | 0.4 | 57.2 | 58.8 | 55.1 | 60.8 | | | |

*Statistically significant. SD: Standard deviation, SE: Standard error, GIC: Glass ionomer cement, CI: Confidence interval, ANOVA: Analysis of variance

This study found that the mean CS of Zirconomer was 181.2 MPa which is second only to that of silver amalgam (256.2 MPa), but higher than that of unmodified GIC (117.9 MPa and 129.8MPa). This increase in compressive fracture strength of Zirconomer can be attributed to the addition of zirconia, which resists compressive forces more effectively than the weak matrix on loading.

In this study, the materials which were tested showed lower DTS than CS. The unmodified GIC Fuji IX and Shofu FX II have DTS (23.2 and 36.0 MPa), respectively. This could be due to the fact that the compressive component may have hindered the propagation of the tensile crack.[13]

The mechanical strength of the GIC is affected by the chemical composition, the size of the powder particles, and its distribution.[19] The setting reaction of GICs is an acid–base reaction forming a salt hydrogel which acts as the binding matrix with glass or Yttria-stabilized zirconia fillers. Upon mixing the acid with the powders, the acid attacks the powders, releasing metal ions. The released metal ions act as cross-linking species, allowing the formation of stable cement. Continued formation of cationic bridges that cross-link the polymer chains which enhance the strength and insolubility of the cement.[20] This process decreases the water content, thereby improving the strength of the cement. Thus, the final mechanical properties of the cement are significantly dependent upon the cross-linking formation during setting.

However, the relative low volume of reinforcing glass particles in GIC does not provide much ability to resist the forces induced on loading. This manifested as fracture of GIC samples relatively at lower compressive loads.[14] In this investigation, Zirconomer showed a DTS of 58.0 MPa. This value is greater than that of the unmodified GIC which is due to the presence of reinforcing fillers along with increased CS which is in accordance with other studies.[21]

The powder in Zirconomer contains fluoroaluminosilicate, zirconium oxide, tartaric acid, and pigments. The homogeneous incorporation of zirconia particles in the glass component further reinforces the material.

The increased strength of zirconomer with improved mechanical properties and behaviour can be attributed. to the addition of crystalline zirconia to glass ionomer which has cross-linked aluminosilicate gel matrix.[22] Zirconia with its stable crystalline structure imparts strength to the set aluminosilicate matrix in restorations.This phenomenon can be considered analogous to the increased strength and improved performance of aluminous porcelain which manifests improved physical properties on account of incorporation of crystalline alumina to amorphous porcelain material.

The Zirconomer consists of nano-sized zirconia fillers which also enhance the material's optical property of translucency which results in a closer shade match to natural teeth. Further, the handling characteristics are superior which allows simple, easy, and fast bulk placement of the material, unlike amalgam. At the same time, it has the strength and durability of amalgam and benefits of glass ionomer-like self-adhesive properties with coefficient of thermal expansion close to dentine. This also reduces the marginal gap formation during the long-term performance of the material which is not present in amalgam in fact amalgam tends to undergo marginal deterioration over a period of time.

The presence of crystalline zirconia in Zirconomer may act in the same way as crystalline alumina in aluminous porcelain which arrests crack propagation and prevents irreversible tensile fracture of the restoration under dynamic loading during masticatory cycles. It should be noted that zirconia is unaffected by oral fluids neither chemically nor physically.

The Zirconomer further provides the advantage of the action of fluoride which is not present in amalgam. Hence, Zirconomer can be preferred as an alternate material in high caries index patients, patients not willing for amalgam restorations, and also to reduce the potential mercury toxicity associated with amalgam.

## CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that silver amalgam has the highest compressive and DTS among all the direct restoratives employed. Zirconomer showed compressive and DTS greater than that of the unmodified GIC such as Fuji IX and Shofu FX II. Although Zirconomer has mechanical properties greater than that of unmodified GICs, further long-term research will be necessary to evaluate its longevity.

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### Conflicts of interest
There are no conflicts of interest.

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