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Evaluation of the Strength of a Novel Bioactive Hybrid Glass Restorative Material

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Abstract

Glass ionomers are routinely placed as caries control restorations due to their bioactive properties, including fluoride release and chemical adhesion to the tooth structure. However, their poor physical properties limit their use to minimum stress-bearing cases and caries-control temporization. A novel bioactive hybrid glass restorative material with improved properties with a resin coating (RCHG) has been developed for a definitive restoration comparable to composite resin. This in-vitro study compared the compressive and flexural strength of resin-coated RCHG to nano-filled composite resin restorative material (NFCR). A total of 40 samples, cylindrical and bar-shaped samples, were fabricated from RCHG and NFCR (n=10). Compressive strength and 3-point bending testing were performed in a universal testing machine. The mean values for each material were statistically compared using an independent t-test at a significance level of $P<0.05$. RCHG had significantly lower mean flexural strength and compressive strength values (57.77 ± 3.95 and 81.52 ± 18.38MPa respectively) than NFCR (201.30 ± 15.25 and 217.55 ± 51.66 MPa, respectively). The investigated RCHG material is still not as reliable in stress-bearing restorations compared to resin composites. However, further testing is needed to appraise the true potential of these bioactive glass materials.

Keywords: Bioactive, Glass hybrid restorative materials, Restorative dentistry, Compressive strength, Flexural strength, Composite resin

Introduction

Nowadays, dentists are shifting from the traditional idea of extension for prevention to a minimally invasive, preventive treatment method (Laske *et al*., 2018; Hasanain *et al*., 2021). This concept includes the development and use of restorative materials with bioactive properties (Abbassy *et al*., 2021). Dentistry has been utilizing the remineralization abilities of fluoride in restorative materials since the development of glass ionomer cement (GIC) and resin-modified glass ionomers (RMGIC) (Nicholson, 2014). Both types of GIC can chemically adhere to the tooth structure, release fluoride, and recharge fluoride, which helps to prevent dental caries (Mulay *et al*., 2022). Thus, these materials are seen as initial versions of bioactive materials used in restorative dentistry (Özcan *et al*., 2021). Unfortunately, their mechanical strength values are lower than other tooth-colored restorative materials, such as resin composites. Although RMGIC has better polishability, compressive strength, and surface hardness, it still cannot surpass composite resin materials' physical and aesthetic properties (Lohbauer & Belli, 2020). Using it as a permanent restoration in stress-bearing situations, like class II cavities in posterior teeth, is not recommended. The Equia restorative system (GC) was introduced in 2011 as a durable material that includes reinforced GIC with a nano-filled resin coating. A new and improved version of the EQUIA Forte Fil® bulk-fill hybrid glass material from GC has been introduced. It boasts chemical adhesion to the tooth structure and superior physical and esthetic properties. This makes it a suitable option for the definitive restoration of Class I, II, and V cavities, and it can be compared to the composite resin-filling materials (Brzović-Rajić *et al*., 2018). The material comprised a high-viscosity glass hybrid with fluoride-releasing, highly reactive fluoro-alumino-silicate (HRFAS) glass particles, conventional fluoro-alumino-silicate (FAS) fillers, and high molecular weight, cross-linked polyacrylic acid matrix better esthetics than its predecessor (Sidhu & Nicholson, 2016). The specially formulated multi-functional monomer-based resin coating material that comes with it is designed to improve the final restoration's toughness, marginal seal, gloss, and smoothness (Miletic *et al*., 2020; Mohammed *et al*., 2022).

Dental restorations must possess high compressive and flexural strengths to function properly in the oral cavity. Flexural and compressive strength testing are essential for assessing mechanical properties. Limited research has been done on the compressive and flexural strength of hybrid glass material coated with resin compared to composite resin for permanent teeth. This study aimed to compare the compressive and flexural strength of resin-coated hybrid glass restorative material (RCHGR) with nano-filled composite resin material (NFCR). The null hypothesis was that there is no significant difference in flexural and/or compressive strength between RCHGR and NFCR.

Materials and Methods

This in-vitro study was exempted by the research ethics committee of the Faculty of Dentistry at King Abdulaziz University, IRB protocol KAU no. 071-03-19. Two light-cured restorative materials (shade A2) were tested in this study; (NFCR) Filtek Z350

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XT and (RCHGR) EQUIA Forte Fil® with EQUIA Forte Coat **(Table 1)**.

Table 1. Materials used in the study.

Material	Manufacturer	Type	Composition
EQUIA Forte Fil®	GC International Corp, Tokyo, Japan	Bioactive hybrid glass	Powder: 95% strontium-fluoro aluminosilicate glass particles, 5% polyacrylic acid Liquid: 40% aqueous polyacrylic acid (Miletic *et al*., 2020)
EQUIA Forte Coat	GC International Corp, Tokyo, Japan	Low-viscosity nano-filled resin	40%–50% MMA, 10%–15% colloidal silica, 0.09% camphor quinone, 30%–40% UMA, 1%–5% phosphoric ester monomer (Miletic *et al*., 2020)
Filtek Z350 XT	3M ESPE, St,Paul, MN, USA	nano-filled methacrylate composite resin	Matrix: UDMA, Bis-GMA, Bis-EMA Fillers:78.5wt%,63.3%vol; 20 nm silica, 5 -11nm zirconia nanoparticle, zirconia/ silica nano agglomerates (0.4-0.6 µm)

Note, MMA, Methyl methacrylates; UMA, Urethane methacrylates; Bis-GMA, Bisphenol A glycidyl dimethacrylate; Bis-EMA, Ethoxylated Bisphenol A di methacrylate; UDMA, Urethane dimethacrylate.

Samples Preparation

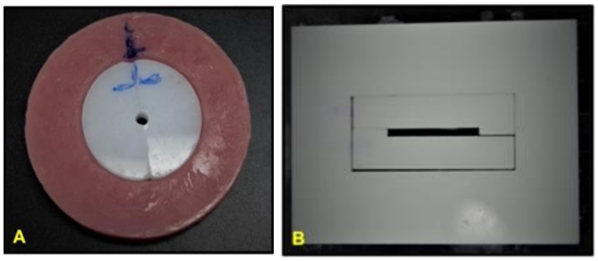
This study involved the preparation of 40 samples in total. A total of 20 samples were made for each material, with 10 samples designated for compressive strength testing (ISO 9917-1 cylindrical samples; 4 × 6 mm) and the other 10 for flexural strength testing (ISO 9917-2 bar-shaped samples; 25 × 2 × 2 mm). The manufacturer's instructions were followed during the handling and curing process rigorously.

RCHGR Samples

EQUIA Forte Fil capsules were shaken to loosen the powder, then activated by the designated plunger. To prepare the capsules, they were triturated using an auto mixer (3M ESPE CapMix, 3M ESPE, St. Paul, MN, USA) for 10 seconds at approximately 4,000 RPM after being clicked once in the applicator. Then, the mixture was applied into 3D-printed molds **(Figure 1a)** and inserted between two glass plates with celluloid strips separating the RCHGR from the glass slab. During the setting process, the glass slabs were held securely to prevent air bubbles and ensure a smooth surface. To finish the samples while removing debris, 600-grit sandpaper was utilized. Next, the EQUIA Forte Coat was applied with a micro-brush and cured with an LED curing light (3M ESPE Elipar, 3M ESPE, St. Paul, MN, USA) for 20 seconds. All finished samples were thoroughly examined for voids or defects, and any samples that were found to be defective were immediately discarded. After the samples had been stored for 24 hours, we used a digital caliper to measure their height and width. Any defective samples were removed from the study.

NFCR *Samples*

A dental plastic filling instrument was used to apply the NFCR Filtek Z350XT in increments of 2 mm. To load the material into the molds **(Figure 1b)** and remove excess composite, the molds were put on a glass slab and covered with a celluloid strip on the top surface. Next, gentle pressure was applied to achieve a smooth surface and consistent thickness. The samples were cured using LED light curing (3M ESPE Elipar, 3M ESPE, St. Paul, MN, USA) for 20 seconds from the top and bottom surfaces through the celluloid strips. Once taken out of the mold, the samples underwent further curing in the middle section. To complete the samples and eliminate any extra material flashes, 600-grit sandpaper was utilized. To ensure accuracy, we used a digital caliper to double-check the height and width measurements of the samples, with a precision of 0.01 mm. Before testing, all samples were stored for 24 hours in distilled water at 37°C to ensure complete polymerization. All finished samples were thoroughly examined for voids or defects, and any samples that were found to be defective were immediately discarded.



a) b)

Figure 1. 3D-printed molds for compressive and flexural strength test sample preparation.

Note: a) compressive strength test mold; b) Flexural strength test mold.

Strength Testing

The 4 x 6 mm cylindrical compressive strength (Cs) samples were loaded until fracture in a universal testing machine (Mini Instron no. 4442, Instron Corp, Canton, MA, USA) at a crosshead speed of 1.0 mm/min (ISO Standard 9917-1) **(Figure 2a)** and Cs was calculated according to the following formula (1):

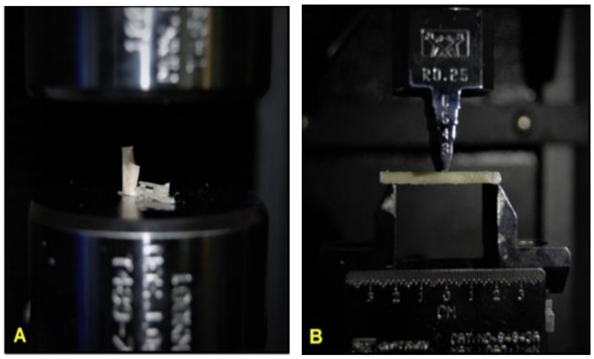
$$C_S = \frac{F}{\frac{1}{4}\pi d^2} \tag{1}$$

The load at fracture is represented by F, while d stands for diameter, and π refers to the specimen height.

The 25 × 2 × 2 mm bar-shaped flexural strength (Fs) samples were subjected to a 3-point bending test until fracture in a universal testing machine (Mini Instron no. 4442, Instron Corp, Canton, MA, USA) at a crosshead speed of 1.0 mm/min (ISO Standard 9917-2) **(Figure 2b)**. Fs was calculated according to the following formula (2):

$$F_S = \frac{3Fl}{2wh^2} \quad (2)$$

Where F is the load at fracture, l is the distance between the supports (=20 mm), w is the specimen width, and h is the specimen height.



a) b)

Figure 2. Strength testing in the universal testing machine (UTM).

Note: a) Compressive strength test until sample completely fractured; b) Sample positioned in UTM for flexural strength 3-point bending test.

Statistical Analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (IBM SPSS Statistics 20.0, SPSS Inc., Chicago, IL, USA). A Kolmogorov-Smirnov Test of Normality was conducted to assess the mean strength values for each group. It was found that all variables tested had a normal distribution. The mean strength (flexural strength (Fs) and compressive strength (Cs)) of the two materials were compared using an independent t-test with a significance level of p<0.05.

Results and Discussion

The two-tailed independent t-test was used to compare the mean compressive and flexural strength (Cs and Fs) of two materials at a significance level of p<0.05. Our results showed that the mean compressive and flexural strength of RCHGR were significantly lower compared to NFCR (p<0.001) **(Table 2)**.

Table 2. Independent t-test comparison of compressive strength (Cs) and flexural strength (Fs) between RCHGR and NFCR.

Material	n	Mean (MPa)	SD (MPa)	t	P- value
Compressive Strength (Cs)					
RCHGR	10	81.52	18.38	7.85	<0.001*
NFCR	10	217.55	51.66		
Flexural Strength (Fs)					
RCHGR	10	57.77	3.95	28.81	<0.001*
NFCR	10	201.30	15.25		

Note. RCHGR is EQUIA Forte Fil with EQUIA Forte Coat, NFCR is Filtek Z350 XT, SD is standard deviation, *statistically significant result.

When it comes to dental restorative materials, they must possess qualities such as strength, safety, aesthetic appeal, bioactivity, permanent bonding, and efficient restoration of form and function (François *et al*., 2021). Stronger materials lead to better stability and lower chances of deformation or fracture, increasing the likelihood of clinical success (Mishra *et al*., 2018). Dental materials undergo strength testing in a lab to ensure durability under clinical forces (Poornima *et al*., 2019). Intraoral masticatory forces can cause fracture failure due to compressive stresses (Attin *et al*., 1996; Alshareef *et al*., 2021). However, the exact critical value remains unknown (Poornima *et al*., 2019). Flexural strength measures how strong a material is and how much it is expected to bend under stress (Mishra *et al*., 2018). Low flexural strength (< 80 MPa) increases the risk of chipping and bulk fractures in Class II restorations, per ISO 4049 standards (Heintze & Rousson, 2012; Standardization, 2019). Newly introduced resin-integrated chemically adhering, bulk-fill, hybrid glass materials (i.e., EQUIA Forte Fil, GC International Corp, Tokyo, Japan) have potential bioactivity and expanded indications for direct restorations (François *et al*., 2021). Its accompanying nano-filled resin surface coating material reportedly increases the filling's resistance to masticatory forces. This is supported by. an in vitro study that tested the influence of resin coating (GC Plus, GC International Corp, Tokyo, Japan) on the GIC filling materials (Bonifácio *et al*., 2012). However, the newly introduced resin-coated material's mechanical properties have not been extensively studied compared to composite resin materials. This study evaluated the 3-point bending and compressive strength of novel hybrid glass bioactive EQUIA Forte compared to conventional nano-filled composite resin materials for posterior teeth. Based on the results, there were significant differences between the two materials (p<0.001), which led to the rejection of the null hypothesis.

The flexural and compressive strengths of the tested nano-filled composite were significantly higher than those of the novel glass hybrid material, even though it was coated with the specially formulated nano-filled resin coating. This corresponds with the results of a 2018 study, where nano-hybrid composite resin had higher compressive and flexural strength than both GIC and a recently introduced fluoride-releasing alkasite composite (Mishra *et al*., 2018). Ideal restorative materials should have mechanical properties comparable to human dentin (around 297.2 MPa) (Piwowarczyk *et al*., 2002). In the current study, NFCR had a mean compressive strength of 217.55± 51.66 MPA, closer to human dentin than RCHGR's mean value (81.52 ± 18.38 MPa). The mean compressive strength of EQUIA Forte Fil was higher than the minimum value required by ISO 9917 standard for pulp capping material (Ranjbar Omrani *et al*., 2021). Therefore, with its fluoride release and chemical adhesion, it might present as a more suitable material for indirect pulp capping restorations stronger than RMGIC base materials. It has been previously observed that the compressive strength of RMGI increases with extended storage (Poornima *et al*., 2019; Yousif *et al*., 2023) and that resin coating increases the compressive strength of EQUIA Fil material (Brzović Rajić *et al*., 2019). Therefore, the compressive strength of RCHGR might likewise increase with longer storage. Further studies into the compressive strength of the material after storage and aging would be recommended. The mean flexural strength of NFCR in the study was higher than the ISO 4049 standard (80MPa) for restorations of posterior teeth with an occlusal component (Standardization, 2019). The RCHGR EQUIA Forte Fil has a mean flexural strength value of 57.77 ± 3.95 MPa, which is lower than the standard but still higher than the previous study's findings of 22.7±6.9 MPa when the material was self-cured (François *et al*., 2021). In a previous report, Equia Forte Fil was found to have greater flexural strength than other GIC materials (Moshaverinia *et al*., 2019). However, the current study showed that its value was not high enough to be on par with composite resin. The previously reported material's bulk fracture failure mode may be due to its low flexural strength (Hesse *et al*., 2016). In this study, the material was exposed to additional light curing, which likely contributed to its increased strength. These findings align with the 2021 study that concluded light-curing bioactive materials results in higher flexural strength than self-curing materials (François *et al*., 2021).

The results of the current study, concluding that composite resins had higher strength than the tested EQUIA Forte Fil with EQUIA Coat and thus are more durable, are in agreement with a recent one-year-long clinical randomized trial where nano-filled composite restorations were more durable than the RCHGR (Balkaya *et al*., 2019). A clinical study conducted in 2016 also reported instances of bulk fracture in resin-coated bioactive filling materials (Hesse *et al*., 2016). However, this contradicts the conclusions of a two-year-long clinical study in 2020, where both glass-hybrid and nanohybrid resin composite were effective options for larger class II restorations (Miletic *et al*., 2020). Additionally, earlier clinical performance studies compared restorations fabricated from initial versions of the EQUIA Forte system with nanohybrid composite restorations. In one of these studies, it was determined that Class I fillings made from hybrid glass material were just as long-lasting as micro hybrid composite resin restorations, regardless of the size of the cavity (Friedl *et al*., 2011). Subsequent clinical studies showed that the RCHGR fillings were also effective in restoring non-carious cervical lesions up to one year and small class II cavities for up to 6 years (Gurgan *et al*., 2015; Vaid *et al*., 2015; Gurgan *et al*., 2017). However, it is advisable to conduct further research to determine the complete physical properties of the novel hybrid glass bioactive filling materials before making any conclusions.

Conclusion

The mechanical properties and characteristics of the materials, such as how they feel and how easy they are to handle, can influence a clinician's preference for one over the other. Eventually, a successful dental material needs to be durable enough to withstand the pressure of chewing and grinding. A material's compressive and flexural strength determines its strength and how long it will last. In this study, it was found that the EQUIA Forte Fil with resin coating is not as strong as the nano-filled composite resin. Therefore, it is necessary to conduct additional research on its mechanical properties before deciding its suitability for use in high-stress-bearing restorations.

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