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Properties of New Glass-Ionomer Restorative Systems Marketed for Stress-Bearing Areas

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Clinical Relevance

The newer glass-ionomer restorative materials marketed for posterior stress-bearing areas may not provide any significant advantage in mechanical properties over other conventional glass-ionomer materials.

SUMMARY

Objectives: The purpose of this study was to evaluate the properties (fracture toughness, surface hardness) of newer conventional glass-ionomer restorative materials that are marketed for posterior stress-bearing areas compared with more traditional glass-ionomer restorative materials marketed for non–load-bearing areas and composite-resin restorative materials.

Methods and Materials: Notched-beam fracture toughness specimens were created in a mold with each tested material (Equia Forte, GC America, with and without a surface coating of Equia Forte Coat; Ketac Universal, 3M/ESPE; ChemFil Rock, Dentsply; Fuji IX GP Extra, GC; Ionostar Molar, VOCO; Filtek Z250, 3M/ESPE; Filtek Supreme Ultra, 3M/ESPE) and fractured using a universal testing machine after 24 hours of storage. Hardness values were determined on the surface of the fracture toughness specimens using a hardness tester. Data were analyzed with a one-way ANOVA and Tukey's post hoc test per property (alpha=0.05).

Results: The composite-resin restorative materials had significantly greater fracture toughness than the glass-ionomer materials. There was no significant difference in fracture toughness between the glass-ionomer materials. The use of a resin coating significantly increased the surface hardness of the newer glass ionomer marketed for stress-bearing areas.

Conclusions: Fracture toughness was not improved with the newer glass-ionomer restorative materials marketed for stress-bearing areas compared to the conventional glass-ionomer materials, however a resin coating provided greater surface hardness.

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INTRODUCTION

For years, clinicians and researchers have sought to find a material to replace missing or weakened tooth structure that best mimics the characteristics of enamel, the hardest and most mineralized substance in the human body.[1] Teeth are subjected to many dynamic conditions ranging from different working movements, thermal insults and challenges, oscillations of pH levels, and parafunctional behaviors. Restorative materials differ in mechanical properties that allow them to withstand forces placed on them during function. Technique sensitivity and operator skill in placement affect long-term clinical success for materials. With these factors in mind, there is not currently one ideal restorative material.[2]

Amalgam is still considered an excellent choice for posterior restorations. Its use has declined for several reasons to include perceived adverse effects of mercury and esthetic factors. In 2013, a global agreement was signed at the Minamata Convention that dictated the phase down in the use of amalgam.[3,4] Composites are clearly more esthetic in appearance than amalgam. However, they wear faster than tooth structure and are subject to possible postoperative sensitivity and microleakage.[2] Compared with use of amalgam, placing composites using a 2-mm incremental technique is more time consuming.[5] Newer low-viscosity flowable bulk-fill composites and higher viscosity conventional bulk-fill composites have been marketed for 4 mm or greater depth of cure. These bulk-fill composite resins tend to be more translucent than traditional composites to allow for greater depth of cure. Bulk placement is more time efficient; however, further clinical research is still necessary to compare the advantages and disadvantages with the gold standard approach of incremental layering.[6]

The use of conventional glass-ionomer cements (GICs) has long been advocated for the primary dentition, for noncarious cervical lesions, and for use in atraumatic restorative treatment approaches. The use of GICs was popularized in the 1970s; however, their use was limited due to poor abrasion resistance, low tensile strength, poor esthetics, and low final hardness.[7,8] GICs exhibited a wear rate five times higher than amalgam and three times higher than composite-resin materials.[9] GIC has many highly advantageous properties such as a similar coefficient of thermal expansion to enamel and dentin, formation of direct chemical adhesion to tooth structure, biocompatibility, bulk placement, and fluoride uptake and release.[7,10] Even with these attributes, the properties of GIC may not be sufficient to overcome the limitations in areas of heavier occlusion.[11] Manhart and others reported that fractures in conventional GIC restorations caused an annual failure rate of 7.2%, which was higher that amalgam (3.0%) or composite restorations (2.2%) in posterior areas.[12]

Newer formulations of glass ionomers have been developed over the last decade with the purpose of mimicking the wear, strength, polishability, and esthetics of composite resins. Equia Fil (GC America, Alsip, IL, USA) is a high-viscosity conventional GIC. The company optimized the polyacid and particle size distribution, which reportedly created a higher cross-linkage of the GIC matrix. Combined with a nanofilled coating (Equia Coat, GC America), it was marketed to yield a restorative material indicated for posterior stress-bearing restorations.[13] Equia Fil was formerly known as Fuji IX GP Extra and Equia Coat was formerly known as G-Coat Plus. The Equia Fil formulation showed significant improvements in fracture strength once coated with Equia Coat.[14] Resin coatings have been implemented to seal surface defects and potentially limit abrasive wear and early material fracture while the GIC matures and reaches peak strength.[10] The fluoride uptake/release potential may be substantially reduced with the application of a surface coating.[15] However, it has been suggested that the fluoride release may be effective in reducing secondary caries in the marginal gap of the tooth–restoration interface and not in the exposed surface of the GIC intended to be protected by the resin coating.[14,16]

The latest generation of conventional GICs marketed for load-bearing restorations consists of products like Equia Forte (GC America) and Ketac Universal Aplicap (3M/ESPE, St Paul, MN, USA). Equia Forte contains a new higher-molecular-weight polyacrylic acid to reportedly create an even higher strength restorative material compared with Equia Fil. The Equia Forte Coat application incorporates a newer multifunctional monomer, which reportedly produces a tougher resin matrix to extend the indications to include stress-bearing class 2 restorations.[17] 3M ESPE recently introduced Ketac Universal Aplicap, which they claim may be used in class 1 and class 2 stress-bearing restorations as long as there is at least one additional support outside the restoration area. For class 2 restorations, they also recommend that the isthmus must be less than half the intercuspal distance. Ketac Universal contains a copolymer of acrylic and maleic acids.[18]

In the present study, these new GIC materials marketed for load-bearing restorations were compared with other GICs marketed for non–load-bearing class 1 and class 2 restorations (Fuji IX GP Extra), non–occlusion-bearing class 1 restorations (IonoStar Molar, VOCO America, Indian Land, SC, USA), semipermanent restoration of class 1 and 2 preparations in posterior teeth (ChemFil Rock, Dentsply, York, PA, USA), and two composite-resin restorative materials, Filtek Z250 and Filtek Supreme Ultra (3M/ESPE). Fuji IX GP Extra is a high-viscosity conventional glass ionomer that was later remarketed as Equia Fil.[19] Ionostar Molar is a new glass-ionomer restorative with improved characteristics that reportedly provides immediate packability.[20] ChemFil Rock is a zinc-reinforced glass-ionomer restorative material. The manufacturer claims that the inclusion of zinc-oxide enhances the setting reaction and increases strength and toughness.[21] The hybrid composite, Filtek Z250 (3M ESPE), and nanocomposite, Filtek Supreme (3M ESPE), were selected based on their different size and distribution of their filler particles.[22]

There is a lack of research to substantiate the marketing claims for the newest generation GICs in load-bearing areas. The purpose of this study was to test various mechanical properties (fracture toughness and surface hardness) of newer GICs marketed for stress-bearing areas compared with more conventional GICs marketed for non–load-bearing areas and composite-resin restorative materials. The null hypotheses tested was that there would be no differences in (1) fracture toughness or (2) surface hardness based on type of restorative material.

METHODS AND MATERIALS

Fracture toughness was determined using a single-edge notched-beam method. To prepare each specimen, a knife-edged split (2.5 × 5.0 × 25.0 mm) stainless-steel mold (Sabri, Downers Grove, IL, USA) was placed on a plastic strip–covered glass slide. Ten specimens of each restorative material were made by inserting the restorative material into the mold until completely filled. Then, the top surface of the mold was covered with a second plastic strip and glass slide to ensure that the end of the specimen was flat and parallel to the opposite surface of the mold. For the composite materials, one side of the specimen was exposed to a light polymerization unit (Bluephase 20i, Ivoclar Vivadent, Amherst, NY, USA) in three separate overlapping increments for 20 seconds each. The adequacy of the light unit's intensity was assessed prior to specimen preparation using a radiometer (Bluephase Meter, Ivoclar Vivadent). Next, the mold was turned over, and the opposite side of the specimen was exposed to the light in a similar manner as described before. The glass-ionomer specimens were allowed to chemically cure for 10 minutes before removal from the mold. One group of Equia Forte specimens were covered with Equia Forte Coat and light cured per the manufacturer's instructions. A resin coat was only applied to the Equia Forte specimens because no other manufacturer of the GIC materials tested in this study recommended the use of a surface coat.

Then, the specimens were stored for 24 hours in humidified air at 37°C in a laboratory oven prior to testing. The height, h, width, w, and the notch depth, a, of the specimens were measured with an electronic digital caliper. The specimens were then fractured using a universal testing machine (Model 5543, Instron, Canton, MA, USA) at a crosshead speed of 1.0 mm/min, with the notch on the tensile side and the loading pin aligned with the notch. Fracture toughness (K_{IC}) was calculated from measurements using the equation:

$$K_{IC} = \frac{3(a/w)^{1/2}[1.99 - a/w(1-a/w)(2.15 - 3.93a/w + 2.7(a/w)^2]FS}{2(1+2a/w)(1-a/w)^{3/2}hw^{3/2}}$$

where S is the span distance (20 mm) between supports and F is the maximum force at fracture.

The fractured specimens from the fracture toughness test were used as the specimens for the surface hardness test. Surface hardness was determined using a Knoop Hardness tester (Leco, LM300AT, St Joseph, MI, USA) under a load of 200 g for 10 seconds. A mean of three measurements was taken from each of the specimens per group.

Statistical Analysis

The mean and standard deviation was calculated for each of the restorative materials for each property. Data were analyzed with a one-way ANOVA and Tukey's post hoc test per property (α=0.05) using statistical software (IBM SPSS, version 24, Chicago, IL, USA).

RESULTS

A significant difference was found between the materials based on fracture toughness ($p<0.001$) or surface hardness ($p<0.001$; Table 1). Filtek Z250 had significantly greater fracture toughness

Table 1: *Fracture Toughness and Surface Hardness of the Tested Materials*[a]

Material	Property [Mean, SD)]	
	Fracture Toughness, $MPa{*}m^{1/2}$	Knoop Hardness, kg/mm^2
Filtek Z250 (3M/ESPE)	1.21 (0.12) A	81.3 (1.9) A
Filtek Supreme Ultra (3M/ESPE)	0.82 (0.20) B	72.8 (1.9) B
Equia Forte and Coat (GC)	0.40 (0.04) C	83.5 (4.5) A
ChemFil Rock (Dentsply)	0.39 (0.03) C	59.4 (0.8) E
Fuji IX GP Extra (GC)	0.38 (0.03) C	70.2 (1.0) BC
Ketac Universal (3M/ESPE)	0.36 (0.04) C	69.9 (2.6) BC
IonoStar Molar (VOCO)	0.35 (0.04) C	62.7 (1.7) D
Equia Forte (GC)	0.33 (0.04) C	69.1 (1.2) BC

[a] *Groups with the same letter per column are not significantly different ($p>0.05$).*

(1.21 ± 0.12 $MPa{*}m^{1/2}$) than Filtek Supreme Ultra (0.82 ± 0.20 $MPa{*}m^{1/2}$), which was significantly greater than glass-ionomer materials. There was no significant difference in fracture toughness between the glass-ionomer materials (range, 0.40-0.33 $MPa{*}m^{1/2}$). Equia Forte with Equia Forte Coat (83.5 ± 4.5 kg/mm^2) and Filtek Z250 (81.3 ± 1.9 kg/mm^2) had the greatest surface hardness and were not significantly different from each other. Values for Filtek Supreme Ultra (72.8 ± 1.9 kg/mm^2), Fuji IX GP Extra (70.2 ± 1.0 kg/mm^2), Ketac Universal (69.9 ± 2.6 kg/mm^2), and Equia Forte (uncoated) (69.1 ± 1.2 kg/mm^2) were not significantly different from each other. ChemFil Rock (59.4 ± 0.8 kg/mm^2) had the lowest surface hardness, which was significantly lower than IonoStar Molar (62.7 ± 1.7 kg/mm^2).

DISCUSSION

With the public desire for esthetic dentistry, it is clear the future will continue to evolve with novel materials being marketed, including newer glass ionomers, all of which would be more esthetic than amalgam. The current study compared fracture toughness and surface hardness of various glass ionomers with two widely used composites.

Mechanical properties, like fracture toughness, contribute to the performance of restorative materials. In the current study, significant differences were found between the glass ionomers and the composites. According to Ferracane, there may be some threshold for mechanical properties below which failure would be more likely, limiting the use of certain materials, such as glass ionomers, in stress-bearing areas. Fracture of the restorative material can be a primary reason for failure. The fracture toughness test relates to chipping and bulk fracture and may be the most critical laboratory factor in the estimation of resistance to intraoral fracture.[23] This current study found that all the tested glass ionomers had relatively low fracture toughness, including the new GIC materials marketed for stress-bearing areas. Hardness has a limited correlation to wear.[23] In a study by Faria and others, an inverse relationship between surface hardness and wear resistance was observed. In other words, a higher surface hardness may correlate with less wear.[24]

The first null hypothesis was rejected. This current study found a significant difference in fracture toughness between the two different composite resins and the five different GICs tested, with Filtek Z250 significantly more resistant to fracture than Filtek Supreme Ultra, both of which were significantly stronger than the GICs. The new glass-ionomer restorative materials marketed for stress-bearing areas, Equia Forte, with or without a resin coating, and Ketac Universal, displayed no significant difference in fracture toughness compared with the other GICs. The incorporation of the new multifunctional monomer in Equia Forte did not produce a significantly tougher matrix, at least based on the results of this study. This study found no statistically significant increase in fracture toughness with or without a resin coating of the Equia Forte. In the literature, however, the effect of resin coating on fracture toughness is somewhat equivocal, with one laboratory study showing no benefit[25] and others showing a significant increase.[14,26] In this current study, the application of the resin coating slightly increased the surface dimensions (width, height and notch length) compared with the other noncoated specimens. However, the increase was less than 100 μm in any dimension and the effect on fracture toughness values would be offset in the formula calculation. The results of this current study compare favorably with results of a laboratory study by Ilie and others and highlight the difference between highly cross-linked restorative resin composites and cement matrices.[27] The fracture toughness of over 69 restorative materials in ten material categories were evaluated. The lowest fracture toughness was found with the GIC materials, followed by microfilled composite resins, resin-modified GICs and flowable compomers, which were not significantly different from each other. The ormocers, packable, and microhybrid composite resins performed statistically similar, reaching the highest fracture toughness.[27]

Differences were found in surface hardness based on restorative material. Therefore, the second null hypothesis was also rejected. More variability was observed between the GICs when tested for surface hardness. Application of the nanofilled resin coat (Equia Forte Coat) to the Equia Forte specimen resulted in a surface hardness comparable to that of the microhybrid composite resin Filtek Z250 and harder than Filtek Supreme Ultra and all of the other GICs. No difference in hardness was observed between Fuji IX GP Extra, Ketac Universal, and Equia Forte (without the resin coat). The incorporation of the new multifunctional monomer in Equia Forte had a relatively minimal effect on surface hardness, at least based on the results of this current study. The results of this study differ somewhat from a previous laboratory study by Al-Angari and others, comparing various GICs.[28] In that study, Fuji IX GP Extra had significantly greater surface microhardness than Equia Fil with a resin surface coating. In this current study, however, the surface hardness of Equia Forte with a resin coat was significantly greater than Fuji IX GP Extra, as expected. Previous laboratory studies have shown an increase of surface hardness after 6 months with resin coated GICs compared to GICs without application of a resin coating.[29] In a clinical study by Turkun and Kanik, the resin coating protected the margins of Equia Fil and created a regular and glossy surface; however, the coatings were worn away in nearly all of the restorations after six months.[9] Similar to this current study, the study by Al-Angari and others found that ChemFil Rock had the lowest surface hardness value.[28] The zinc reinforcement of ChemFil Rock did not provide any apparent increase in fracture toughness or surface hardness in this current study. ChemFil Rock and IonoStar Molar exhibited relatively low surface hardness and they are only marketed for non–load-bearing occlusal restorations in posterior teeth.

Although no clinical studies are available evaluating Equia Forte, a recent six-year clinical study by Turkun and Kanik found greater color match, marginal adaptation, anatomic form, and retention rates with Equia Fil, marketed for stress-bearing areas, compared with another conventional glass-ionomer restorative material, marketed for non–stress-bearing areas (Riva SC, SDI, Baywater, Australia).[9] However, in a recent study by Klinke and others, the number of unsatisfactory Equia Fil restorations according to the FDI World Dental Federation criteria was determined to be relatively high in two-surface class 2 restorations and even higher in three-surface class 2 restorations, with observable chipping and fractures likely related to lower strength properties.[30] In a four-year study by Gurgan and others, failure rates for a composite resin (Gradia Direct, GC America) in class 1 and 2 restorations were 0% compared with 7.7% for Equia Fil.[13] Basso and others found greater chipping and failures in the marginal proximal crest of wider restorations in their four-year clinical study of Equia Fil.[7] Conclusions from a retrospective clinical study suggested that Equia Fil should be limited to class I and smaller class II restorations if used in load-bearing restorations.[8] Radiographically, progressive loss of GIC material (Fuji IX GP) in proximal areas just below the contacts in class 2 restorations was commonly observed in a six-year retrospective study.[31]

GICs have been shown to be effective for the treatment of class V lesions, for use in primary teeth, and for use in atraumatic restorative techniques. They have been considered for use in non–stress-bearing locations and for a nonpermanent restoration in stress-bearing areas. Recently, GICs with newer formulations, such as Equia Forte and Ketac Universal, have been marketed for stress-bearing areas. This study observed lower fracture toughness and generally less hardness of the GICs compared with the composites tested. Application of an unfilled resin coating may improve the surface hardness to allow for the GIC to mature. Further developments are needed in the formulation of GIC restorative materials to predictably extend their indications in larger stress-bearing areas in posterior teeth. Clinical studies need to be conducted to determine the effectiveness of both formulation changes, as well as resin surface coating for newer GICs as definitive restorative materials.

CONCLUSIONS

The newer GIC restorative materials marketed for posterior stress-bearing areas did not demonstrate any advantage in fracture toughness over other conventional GIC materials. However, the use of a resin coating significantly increased the surface hardness of the newer GIC, Equia Forte, to be similar to microhybrid composite-resin materials tested.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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