

INTRODUCTION

Composite resins have become the materials of choice for posterior restorations for many patients as a result of demands for esthetics, and of increased concern over the toxicity of mercury in amalgam. Dental composite resins consist of a dimethacrylate matrix polymer filled with glass particles. The fillers are coated with a silane coupling agent to join the fillers to the matrix. Manipulation of filler percentages and types will affect the strength of the composite. Silica, zirconia, lithium, and ytterbium are examples of fillers that are added. Changing the size and shape of fillers also will affect composite strength. Mixtures of two or more types of filler particles produce subclasses of resin composites known as hybrid and microfilled.^{1,2}

Polymerization contraction during the curing of composites is a major drawback of these materials. This contraction ranges from 2 percent by volume to 6 percent by volume³ and can give rise to stresses and gaps that can lead to postoperative sensitivity, recurrent caries, marginal discoloration, enamel cracks, and cuspal strain.⁴⁻⁷

Several techniques have been tried to counter the polymerization stresses.⁸ One such technique is to use low-elastic modulus liners under the composite. Potential liner materials include glass ionomer cements, resin-modified glass ionomer cements, and flowable composites. These liners act as a buffer layer that relieves some contraction stresses.⁸

Some studies have shown that this lining layer reduces the microleakage.^{9,10} On the other hand, studies have failed to demonstrate reductions in leakage.^{11,12}

In a retrospective study done by Opdam et al.,¹³ it was shown that posterior composite resins placed as one layer had a higher clinical survival than posterior composite resins placed with a resin-modified glass ionomer liner. Composite resins have higher elastic modulus than resin-modified glass ionomer, so that the question of interest is whether a low elastic modulus liner affects the strength of the restoration. Such a reduction in strength could explain the decrease in the clinical survival.

The aim of this study was to test the hypothesis that a dental restorative material of monolayer resin composite has a higher flexural strength than a bilayer liner/resin composite. The null hypothesis is that the flexural strength of the monolayer composite is not different from that of a bilayer composite, in which the two layers are a composite resin and a low-modulus liner.

REVIEW OF LITERATURE

Composite resin consists of inorganic filler, such as silica dioxide, which is embedded in a weaker matrix such as bisphenol A-glycidyl methacrylate or urethane dimethacrylate. Silane as a coupling agent is used to enhance the bond between these two components. An initiator system is also included.^{13, 14}

Inorganic fillers play a role in classification of dental composites. The classification is dependent on the size, shape, and distribution of the fillers. There are microhybrid, microfilled, packable, flowable nanocomposite, laboratory, and multipurpose composites.¹⁵

Composite resin restorative materials have many advantages, including the ability to conserve tooth structure and to provide esthetic restorations.¹⁶ One major disadvantage of these materials is that the matrix polymer contracts during polymerization. This contraction produces polymerization stresses that can lead to marginal gaps and subsequent leakage.¹⁷⁻²²

Polymerization stress can be lowered by one of the following approaches:

1. Selection of cavity preparation.²³
2. Incremental placement.²⁵
3. Using chemically cured composite resin in the proximal area to minimize the shrinkage at the gingival margin.²⁶
4. Use of low-modulus liners. The liner stretches easily, so that the total stress within the composite is reduced; a critical stress reduction is in the composite-tooth interface. As a result, the bond across the interface is less likely to fail.^{24,30,31}

In the past, liners were used to isolate the pulp, to induce reparative dentin formation, and to neutralize acids.²⁷⁻²⁹ They also have other purposes, such as decreasing pulpal sensitivity; sealing the dentin; improving adaptation to cavity walls (for low viscosity liners that wet the dentin); adhering to tooth tissue, and protecting through fluoride release.³²

An array of liner materials has been used. Although low in compressive strength, calcium hydroxide has the ability to induce reparative dentin. Flowable composite has a higher modulus of elasticity than many liners, and when used with dental adhesives, flowable composite adheres to tooth structure (many liners have little or no adhesion to tooth structure).

Resin-modified glass ionomer liners have the advantages of being self-adhesive, and of exhibiting coefficients of thermal expansion similar to those of natural teeth. They also exhibit a low modulus of elasticity and fluoride release.³³

Resin-modified glass ionomers (RMGIs) were introduced in the late 1980s. Like glass ionomer cements, RMGIs are produced by mixing a glass powder with a polyacid dissolved in water. RMGIs are like glass ionomer cements (GIs), except that a polymerizable, water-soluble polyacid (often HEMA) has been added to the liquid component. Compared with glass ionomer, the resulting cement is less susceptible to degradation after early water exposure; stronger; capable of stronger bonding to enamel and dentin, and less likely to leak.^{34, 36}

RMGIs were classified by Mclean and Wilson into three types according to their usage:^{37, 38}

Type I: Luting and bonding materials. Used for luting crowns, bridges, and orthodontic brackets, these cements set quickly and exhibit low film thicknesses.

Type II: Restorative cements. This type is sub-divided into two categories: 1) esthetic restoratives, and 2) wear-resistant restoratives.

Type III: Lining and base cements; fissure sealants. These are stiffer and will set rapidly. In the late 1990s, packable or high-viscosity GICs were introduced to the market.³⁹

CHARACTERISTICS OF RMGI

1. Fluorine is incorporated in the glass particles. Some fluorine is released as fluoride ions when the polyacid attacks the glass. These fluoride ions do not participate in the setting reaction, and consequently, their release will not weaken the cement.⁴⁰ Fluoride reservoir is high in the first 24 h; then, it drops rapidly during the first week.^{42,43} The fluoride release rate will drop from 100 percent on the first day to 12.5 percent by the end of the first week.^{44, 45} and then the release rate remains stable for 10 days⁴⁵ to 3 weeks.⁴⁶ RMGICs continue to release fluoride in small amounts for years.⁴⁷

2. Biological properties: In a study done by Costa et al.⁴⁸ to evaluate the pulpal response when RMGI was used as a direct pulp capping agent, it was found that the RMGI cement promoted pulp healing through cell-rich fibro dentin and tertiary dentin. In addition, calcified barrier formation was observed at 60 days after placement. On the other hand, Murray et al.⁴⁹ found that 22.2 percent of pulps directly capped with RMGI cement showed bacterial contamination.

SANDWICH TECHNIQUE

McLean et al.⁵⁰ introduced the sandwich technique in 1985. In this technique, composite resin and GI cement are used as enamel and dentin, respectively. The result is a composite-laminated GI cement, or a sandwich restoration.

Two different types of sandwich restorations have been described. The first is a closed-sandwich restoration, in which the base is enclosed by composite resin. The second is an open-sandwich technique, and the cement is opened to the oral cavity to facilitate fluoride release. This is recommended in high caries-risk patients.⁵¹

In 1990, Kemp-Scholte and Davidson⁵² evaluated the polymerization stress relief when they applied the resin composite (RC) over a thin layer of RMGI cement. They found a polymerization stress reduction of between 18 percent and 50 percent when they used 5-mm RC over thin layers of RMGI. In 1994, Ikemi and Nemoto⁵³ demonstrated that the stress relief is about 50 percent when they cured 4-mm RC over 1-mm RMGI cement. In another study, Tolidis et al.⁵⁴ compared the volumetric contraction of RC alone and in conjunction with RMGICs as liner; he found that the lining decreased the contraction by 41 percent.

In 1994, Hotta and Aono⁵⁵ evaluated the bond strength between the cement and dentin on one side and the cement with the composite resin on the other side. They used two cements, conventional GI cement and another RMGI. The study showed that those RMGIs showed greater adherence and better tensile strength than the conventional GICs. Triana et al.⁵⁶ in 1994 confirmed this result. In 1994, Bell and Barkmeier⁵⁷ stated that bond strength is higher with RMGIC than with the conventional cement.

Andersson et al.⁵⁸ conducted a study to evaluate the adaptation between enamel/dentin and class II open RMGI cement/RC, and between enamel/dentin and RC alone. They found that interfacial adaptation of RMGIC to dentin/enamel was better than that of the RC.

CHARACTERISTICS OF LINERS

1. Polymerization contraction of RMGICs as liner. Bryant and Mahler⁵⁹ measured the volumetric contraction of three conventional GICs; two restorative RMGI cements; an RMGI with lining/adhesive consistency; three RCs, and two compomers. They found that conventional GICs and RMGICs have volumetric contractions that are similar to RC and compomers.

2. Marginal adaptation of the lining material to cavity walls.

In 1996, Trushkowsky and Gwinnett⁶⁰ compared marginal adaptation of class V cavities lined with RMGI cements or GIC and restored by RC. They found minimal or no microleakage at both enamel and gingival walls. Besnault and Attal⁶¹ compared leakage in class II RC restorations and open-sandwich restorations in a simulated oral environment. The results of this study indicated that RMGICs showed better tolerance towards temperature and humidity than did the direct composite restorations. The latter showed increased silver penetration, which indicated more leakage.

In 2003, Chung et al.⁶² in an in-vivo study evaluated the ability of lining materials to reduce the internal voids formed by contraction stresses. They used extracted molars and divided the teeth into 14 groups, one group for direct composite, and the other group for sandwich techniques using different liners (RMGICs, compomers, and flowable composites). They found better marginal adaptation for RMGICs, but in general, more porosity in deep restorations.

In an in-vitro study, Haller and Trojanski⁶³ evaluated the marginal quality of dentin-bonded resin composite class II restorations with and without an RMGIC liner. All restorations were bonded using a multi-step dentin bonding system. Presence or absence of the liner had no effect on the marginal quality. In addition, using the liner

did not reduce the volume of resin composite utilized, so that there was no large difference in C-factor.

3. Clinical behavior of RMGIs. Aboush and Torabzadeh⁶⁴ monitored the clinical behavior of class II sandwich restorations made with RMGI cements/RC for one year. They varied the thickness of resin composite. The thickness was measured both clinically and in the laboratory. They accepted the results and concluded that the open-sandwich technique was an acceptable technique for class II restorations.

Vilkins et al.⁶⁵ in 2000 observed RMGIC/RC open-sandwich Class II restorations and Class II RC restorations in molars for two years. They evaluated the restorations annually using bitewing radiographs and photographs. The results indicated that there was no significant difference between the two types of restoration regarding anatomic contours, marginal adaptation, secondary caries, and discoloration, but the RC showed more postoperative sensitivity.

4. Mechanical properties. Brantley et al.⁶⁶ studied the mechanical properties of glass ionomer cements. They found that flexural strength (FS) and diametral tensile strength (DTS) are higher for RMGI cements than for GI cements. On the contrary, RMGI cements have lower Knoop hardness (KH) values and wear resistance than GI cements. RMGICs exhibited plastic deformation prior to fracture, while the GI cements showed brittle fracture behavior.

Ellakuria⁶⁷ measured surface microhardness of GI cements and RMGICs after storage for 12 months in water. The addition of resins to the GIC did not appear to improve the surface microhardness of these materials. In 1996, Uno et al.⁶⁸ measured the diametral tensile strength of four RMGICs, GI cement, and RC after 1 day, 7 days, 15 days, 30 days, 90 days, 180 days, and 365 days. The RMGICs had better DTS than the GI cements, but lower DTS than the RC. Long-term storage had little effect

on the mechanical properties. Xie et al.⁶⁹ measured mechanical properties of RMGI cement and GI cements after “dry” storage for seven days at 70-percent humidity. They found the RMGI cements had much higher FS and DTS than the GI cements, but that the compressive strengths (CS) of the RMGI cements were not generally higher than those of the GI cements.

In a retrospective clinical study done by Opdam et al.,¹³ the monolayer RC posterior restoration was compared with the bilayer (sandwich technique) using RMGICs as liner for RC posterior restorations. They found that the monolayer of RC has higher clinical survival rate than the bilayer (sandwich technique). However, there are no in-vitro studies testing the mechanical properties for the bilayer restoration.

The goals of this study were to compare the flexural strengths of monolayer RC versus bilayer, and to compare the effects of three different liners.

MATERIALS AND METHODS

The materials used in this study are listed in Table I. The materials were used singly or in pairs to form eight different groups of specimens (Figures 1 and 2). Group 1 was a monolayer specimen made entirely with a nanohybrid resin composite (control); (Tetric EvoCeram, Ivoclar Vivadent, NY) (Figure 3). The next three groups were bilayer specimens made with the Group 1 resin composite (RC) layered on top of one of three different liners: Group 2, an RMGI (Vitrebond LC liner, 3M ESPE, St. Paul, MN) (Figure 4); Group 3, another RMGI (GC Fuji Lining LC, GC America, Jefferson, GA) (Figure 5); and Group 4, a flowable RC (Tetric EvoFlow, Ivoclar Vivadent) (Figure 6). The RMGI cements were products used by Opdam et al.¹³ in their nine-year clinical trial comparing closed-sandwich and RC-only Class II restorations.

Each group contained 12 specimens. Groups 1 through 4 were aged in water for 24 h. An identical set of 4 groups was aged in water for 30 days. In the second set, Group 5 was identical to Group 1 in the 24 hours set, Group 6 to Group 2, Group 7 to Group 3, and Group 8 to 4. The product packages used are shown in Figure 3 through Figure 6. The 24-h immersion time was selected to allow for completion of nearly all polymerization shrinkage.⁷⁰ The 30-d storage time was to evaluate the effects of water absorption.⁷¹

SPECIMEN PREPARATION

Monolayer samples: Beam specimens (25×2 ×2 mm) were fabricated with the use of a stainless steel split mold (Figure 7). The mold was cleaned, lubricated with polytetrafluoroethylene (PTFE Release Agent), and then dried with canned air (Dust

of Falcon). The lubricant was applied twice. The mold was placed over a glass slab and a strip of polyethylene terephthalate (PETP)(Mylar; Du Pont, DE) was interposed between the mold and glass slab. Then, the composite material was inserted with a spatula in increments. The resin was covered with another PETP strip and a glass slab was gently pressed against the mold to extrude excess material before polymerization. The glass plate was removed and the composite cured with a quartz-tungsten-halogen unit light-curing source (SDS Kerr). The light power density was verified with a radiometer and found to be greater than 800 mW/cm^2 . Specimens were polymerized by light-curing for 30 seconds each at three, overlapping points down the length of the bar. Samples were then stored at 37°C and 100-percent humidity in an incubator for 15 minutes; subsequently, specimen surfaces were ground with 2000-grit abrasive papers to remove flash. All specimens were stored for 24 hours in distilled water (from Millipore Synergy UV system) at 37°C .

Bilayer samples: The mold (Figure 7) for the monolayer bars was used to fabricate bilayer bars. The mold was cleaned, lubricated with dry release (PTFE Release Agent), and dried with canned air (Dust of Falcon). The lubricant was applied twice. The mold was placed over a glass slab and a PETP strip was interposed between the mold and glass slab. For both the RMGI liners, the powder-to-liquid ratio used was 1:2. The powder and liquid were mixed using a plastic spatula on a paper pad.

Figure 8 shows the syringe (BD Tuberculin Syringe; NJ) that was used. Note that it is equipped with a special dispensing tip (3M ESPE, St. Paul, MN). The mixed paste was loaded into the syringe to the 1-cc level. The piston was pushed in 0.5 mm to fill the mold to the 0.5-mm level. Immediately after filling the mold, the liner was cured for 30 seconds each in three overlapping areas down the length of the bar. Then

a second layer, the RC layer, was inserted with a spatula in increments. The resin was covered with another PETP matrix. A dispensing tip, a glass slab, was gently pressed against the mold to extrude excess material before polymerization. The bars were polymerized by light-curing for 30 seconds each at three, overlapping points. Samples were stored at 37°C and 100-percent humidity in an incubator for 15 minutes. Then, the specimens' surfaces were smoothed with wet, 2000-grit abrasive papers to remove flash. All specimens were stored for 24 hours in distilled water (from Millipore Synergy UV system) at 37°C.

The specimens were fractured in a three-point flexure using a universal testing machine (Instron; Norwood, MA) with a crosshead speed of 1 mm/min. A 2.5 kn load cell detected the fracture load (Figure 9).

The thickness of each layer was calculated on both ends of the fracture site using a measure scope (Nikon Measure Scope UM-2) and the average for the thickness on both sides was taken for each specimen.

Second set: The 30-day groups were stored at 37°C and 100-percent humidity in an incubator. The specimens were thermocycled in thermocycling machine 2500 times, between water baths at 7°C and 48°C with a 30-second dwell time and a 10-second transit time prior to testing the strength after 30 days.

FLEXURAL STRENGTH MEASUREMENTS

The fracture load of the beam was determined using a three-point bending fixture and an Instron universal machine. The span length (L in Figure 11) between the two lower supports was 20 mm. The failure stress calculation of monolithic specimens is described in the Appendix. The resin composite layer was placed under compression and the liner layer was placed in tension for the bilayer specimens. The

flexural strength of bilayer specimens was calculated using the transformed beam theory^{73,74} (Appendix).

Statistics of the flexural strength measurements were summarized for each of the eight treatment combinations: four (4) types of lining exposed to two (2) storage times; two-way analysis of variance (ANOVA) with interaction between the factors was used to evaluate the effects of lining and storage time on fracture strength. A 5-percent significance level was used for all tests. Considering that the interaction effect was significant, pair-wise comparisons of the treatment combinations were examined for significance using the Fisher's Protected Least Significant Differences method. The distribution of the fracture strength measurements was examined, and no transformation was necessary to satisfy the assumptions required for the ANOVA.

SAMPLE SIZE JUSTIFICATION

Based on a published study³⁶ and a pilot study, the within-group standard deviation for flexural strength was assumed to be 12 MPa. With a sample size of 12 samples per treatment combination (96 total samples for the 8 treatment combinations), the study had 80-percent power to detect a flexural strength difference of 15 between any two groups, assuming a two-sided test at a 5-percent significance level for each test.

RESULTS

For the control group, the mean flexural strengths for Tetric EvoCeram at 24 h and 30 d were 81.36 ± 3.99 MPa and 68.41 ± 2.11 MPa, respectively. For the bilayer groups, the mean flexural strengths for Tetric EvoCeram and Tetric EvoFlow at 24 h and 30 d were 85.26 ± 4.28 MPa and 76.63 ± 4.59 MPa, respectively. For the bilayer groups; the mean flexural strength for Tetric EvoCeram and GC Fuji lining LC at 24 h and 30 d were 25.46 ± 3.52 MPa and 27.87 ± 2.91 MPa respectively. For the bilayer groups; the mean flexural strength for Tetric EvoCeram and Vitrebond at 24 h and 30 d were 29.09 ± 1.54 MPa and 37.00 ± 3.28 MPa respectively (Table 3).

FLEXURAL STRENGTH FOR 24 HOURS VS. 30 DAYS

The interaction between lining and time was significant ($p = 0.0128$). When comparing 24 h (81.36 ± 3.99) and 30 d (68.41 ± 2.11) flexural strengths for the monolayer (the unlined RC), the null hypothesis of no difference was rejected ($p = 0.0098$). The RC lined with the flowable RC also exhibited a trend toward higher flexural strength at 30 d (85.26 ± 4.28 for 24 h versus 76.63 ± 4.59 for 30 d) but the difference was not statistically significant ($p = 0.0761$).

Thirty days of thermocycling and water absorption did not significantly change the flexural strength of either RMGI cement from that observed at 24 h and 30 d (bilayer with Fuji 25.46 ± 3.52 for 24 h versus 27.87 ± 2.91 for 30 d) and (bilayer with Vitrebond 29.09 ± 1.54 for 24 h versus 37.00 ± 3.28 for 30 d).

FLEXURAL STRENGTH FOR 24-HOUR GROUPS

Table 3 shows the 24-h data. After 24 h in water, both the nanohybrid RC and the nanohybrid RC lined with the flowable RC exhibited relatively high flexural

strengths and these strengths were not significantly different from one another ($p = 0.43$). When the nanohybrid RC was lined with either RMGI cement liner, the flexural strengths at 24 h were relatively low and these strengths were also not significantly different from one another ($p = 0.48$).

FLEXURAL STRENGTH FOR 30-DAY GROUPS

Table 3 shows the 30-d data. As was the case at 24 h, both the unlined RC and of the RC lined with the flowable RC failed the null hypothesis that there would be no significant difference in their flexural strengths and in those of the hybrid RC lined with either liner (for all four pairs $p = 0.0001$). Although the flexural strength of the RC lined with the flowable RC was higher than the unlined RC, the difference was not large enough to allow the null hypothesis to be rejected ($p = 0.0909$). Similarly, in spite of seemingly larger flexural strengths when the bars were lined with one of RMGICs, the difference was not large enough to reject the null hypothesis of no difference ($p = 0.0610$).

TABLES AND FIGURES

TABLE I
Materials used

Material	Type	Powder	Liquid	Mfturer	Batch No.
Tetric EvoCeram	Nano Hybrid RC	Dimethacrylates Barium glass, ytterbium trifluoride		Ivoclar Vivadent	L15338
Vitrebond LC Liner	RMGI	Fluoro-alumino-silicate glass	Polyalkenoic acid	3M ESPE	7510
GC Fuji Lining LC	RMGI	Alumino-silicate glass	Polyacrylic acid	GC America	Lc0811051
Tetric EvoFlow	Flowable RC	Dimethacrylates Barium glass, ytterbium trifluoride		Ivoclar Vivadent	L08449

TABLE II

Elastic modulus of the materials tested

Material	Specimen	E (GPa)
GC Fuji	1	10.0
GC Fuji	2	10.0
Tetric EvoFlow	1	18.0
Tetric EvoFlow	2	18.0
Tetric EvoFlow	3	18.0
Vitrebond	1	10.0
Vitrebond	2	10.0
Tetric EvoCeram	1	18.3
Tetric EvoCeram	2	17.6

TABLE III

Flexural strength values after 24 h and 30 d

Lining	Time	N	Mean	SE	Min	Max
			(MPa)	(MPa)	(MPa)	(MPa)
Tetric Evoceram +Teric EvoFlow (Bilayer)	24 h	13	85.26	4.28	56.33	109.43
Tetric Evoceram + Teric EvoFlow (Bilayer)	30 d	13	76.63	4.59	37.02	99.22
Tetric Evo Ceram (Monolayer)	24 h	12	81.36	3.99	63.89	104.47
Tetric Evo ceram (Monolayer)	30 d	13	68.41	2.11	54.43	79.73
Tetric Evoceram +Vitrebond (Bilayer)	24 h	11	29.09	1.54	18.01	36.27
Tetric Evoceram +Vitrebond (Bilayer)	30 d	13	37.00	3.28	18.52	53.44
Tetric Evoceram +Fuji (Bilayer)	24 h	12	25.46	3.52	11.74	59.10
Tetric Evoceram +Fuji (Bilayer)	30 d	13	27.87	2.91	10.48	46.43

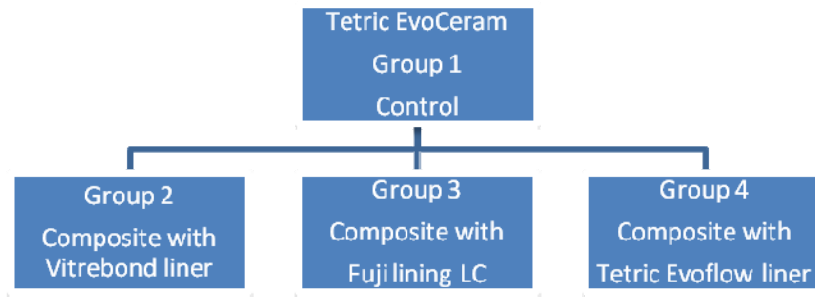


FIGURE 1. Groups stored for 24 h.

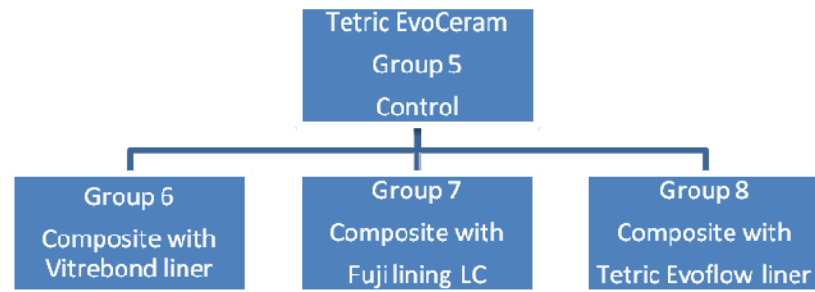


FIGURE 2. Groups stored for 30 d.



FIGURE 3. The nanohybrid resin composite (Tetric EvoCeram) used in all groups.



FIGURE 4. The resin-modified glass ionomer cement (Vitrebond LC Liner) used as the liner material in Groups 2 and 6.



FIGURE 5. The resin-modified glass ionomer cement (GC Fuji Lining LC) used as the liner material in Groups 3 and 7.



FIGURE 6. The flowable resin composite (Vitrebond LC Liner) used as the liner material in Groups 4 and 8.

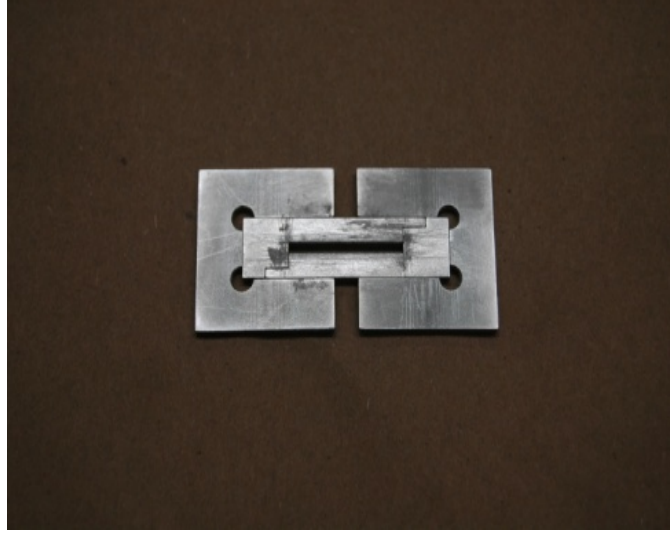


FIGURE 7. The stainless steel split mold used to make monolayer and bilayer bars for flexural strength tests.



FIGURE 8. Syringes (BD Tuberculin) with slip tips.



FIGURE 9. Mechanical testing machine (MTS) ready to fracture test bars in three-point flexure.

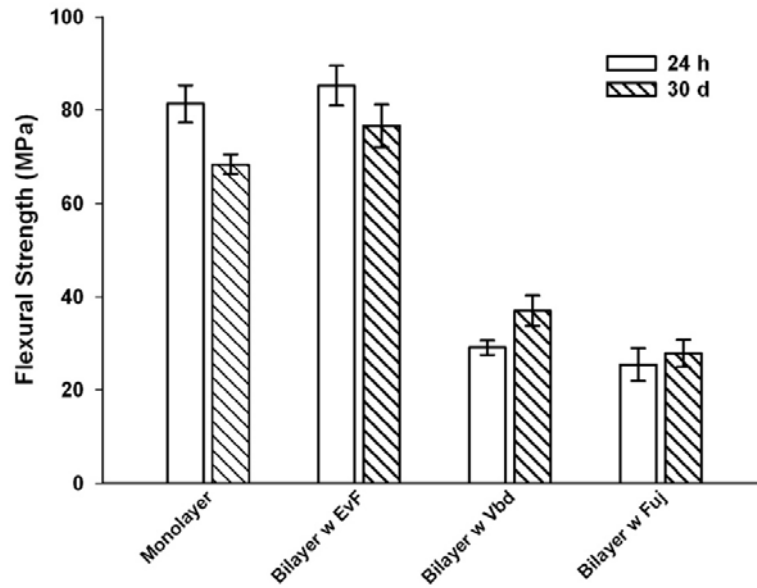


FIGURE 10. Mean flexural strength for 24-h and 30-d groups. Error bars are plus and minus one standard deviation. Bilayer with Evf is Tetric Evoceram resin composite with Tetric Evoflow liner; bilayer with Vbd is Tetric Evoceram resin composite with Vitrebond liner; bilayer with Fuji is Tetric Evoceram resin composite with Fuji LC liner.

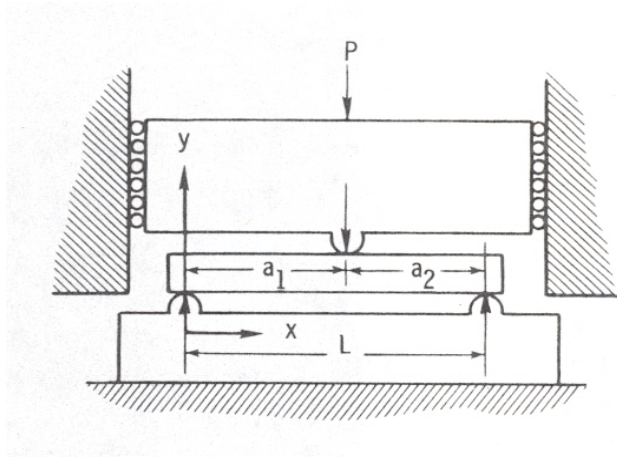


FIGURE 11. Three-point bending fixture. The lower layer is on tension. Where a_1 and a_2 are beam dimensions; B is beam width, P is the maximum contact pressure at load applications point, and L is the outer span length.

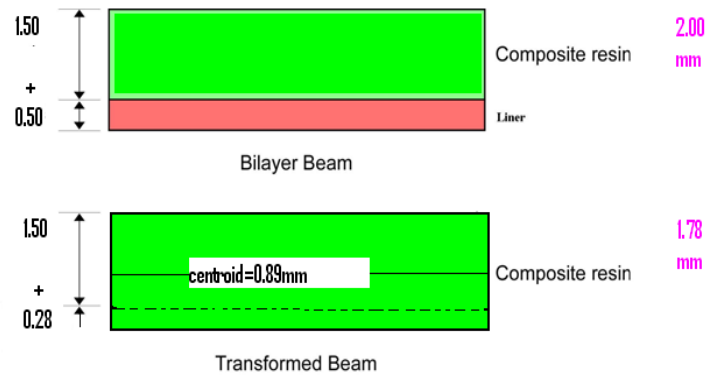


FIGURE 12. Illustration of the concept of using a transformed composite beam to calculate the centroid, and ultimately the flexural strength, of a bilayered beam.

DISCUSSION

Flexural strength is very important for resin composites, because it is one measure of the ability of materials to resist fracture. Flexural strength is the “maximum stress a material can resist before failure when subjected to a bending load.”⁷³ It is a complex stress; the upper part of the material will be subjected to compression stress, while the lower part is subjected to tension stress.⁷⁵

The international standard for direct filling resins, ISO 4049, includes a flexural strength test.⁷⁶ For a material to pass the test, the flexural strength must be larger than N, where

$$N = (E \times 0.0025) + 40$$

Where E is the flexural modulus of the material.

A polymer-based restorative material used on occlusal surfaces satisfies the ISO requirement for flexural strength, when the mean flexural strength is not lower than 50 MPa.⁷⁶

In the present study, the mean flexural strength of the monolayer material (the unlined RC) and the RC lined with the flowable RC both satisfied the minimum requirement for the flexural strength of the ISO. On the other hand, the mean flexural strengths of the RC lined with either of the RMGICs did not reach the ISO’s minimum requirement.

The results of the present study are consistent with those of the clinical trial of Opdam et al.¹³ In that study, RMGI liners reduced the fracture resistance of RC restorations.

There are no in-vitro or in-vivo studies comparing the monolayer and bilayer composite. The present study was in agreement with the study of Gaengler et al.⁷⁷ who evaluated the clinical long-term success of the closed sandwich technique for posterior composite after 10 years. In addition, the flaw size and finishing procedures have important roles in the failure of composites. In the study done by Taskonak⁷⁴ to evaluate the fracture features and failure stresses for ceramics, he found that the flaws play a role in the failure of ceramics.

FLEXURAL STRENGTH FOR 24 HOURS VS. 30 DAYS

The decrease in flexural strength for the unlined RC and the RC lined with the flowable RC could have been related to the following: the elution of the unreacted resin monomers to the surrounding environment, followed by water absorption in the resin occupying the spaces created by the eluting monomer. Also, this procedure needs about one week to one month to be completed. During this time, filler particles are released, lowering the values of the composite's mechanical properties,^{78-79, 95-97} which are affected by the concentration of filler.⁸⁰

The present results showed that there is a significant interaction between the material and time, agreeing with the findings of Attar et al.⁸⁰ Flowable RCs also showed a decrease of flexural strength over time.

The present results show that RMGI cements do not weaken with time, and in fact, could be strengthening. The chemical reaction of RMGI continues for a longer time after initial polymerization, and this duration makes the cement stiffer and stronger over time. Additional acid-base reactions occur by the slow formation of aluminum polycarboxylates, which contribute to the reinforcement of RMGI. In addition, the material is light-cured, allowing some additional, radical reactions adding strength to resin-modified glass ionomers.⁶⁸

The aging mechanism of GIC is somewhat complicated. In a study by Cattani-Lorente et al.,⁸¹ it was reported that the behavior of GIC is complex. Some materials showed an increase in strength, while a decrease was observed for other materials. The increase was related through the additional cross-linking, whereas weakening was related to the plasticizing effect of the water.

FLEXURAL STRENGTH AT 24 HOURS

The RC used in the present study, Tetric EvoCeram, is a nano-filled composite. The high flexural strength found for Tetric EvoCeram is comparable to that reported by Beun et al.,⁸² who concluded that nanotechnology can produce composites with exceptionally high flexural strengths.

Flowable composites used in dentistry exhibit mechanical properties that are 60 percent to 90 percent of the values shown for more viscous, conventional RCs.⁸³ Flowable composites are used as liners, because of their ability to adapt into cavity walls and to fill irregularities. The result is a tooth-liner interface that contains fewer voids.^{84, 85} The significantly high flexural strengths observed in this study are consistent with a study of Ire et al.,⁸⁶ in which the flexural strengths of flowable composites were compared with those of a conventional composite. They found that flowable composites had flexural strengths ranging from 80 percent to 140 percent of those of conventional composites. They suggest that the flowable RCs are more resistant to crack propagation than the conventional RCs. Some data in the literature suggests that flowable RCs should be expected to display inferior flexural strengths. For example, Bayne et al.⁸³ found that the flexural strengths of flowable composites ranged from 60 percent to 90 percent of values shown for conventional RCs. Attar et al.⁸⁰ found flexural strengths for flowable RCs that were lower than those exhibited by conventional RCs.

Dental RCs have higher flexural strengths and elastic moduli than resin modified glass ionomer (RMGI cements). The results of this study are consistent with the study of Li et al.,⁸⁷ who examined the flexural strength of three RMGI cements and one conventional GI cement and two RCs. They found that the flexural strength of RMGI was significantly lower than that of the RC.

FLEXURAL STRENGTH FOR THE 30 DAYS

The results of this study are also consistent with those of Kanchanvasita et al.,⁸⁸ who also found that the flexural strength for Vitrebond is higher than that of GC Fuji LC.

The sandwich technique has been used to buffer the contraction stress of composite resin. In the literature, studies have supported the idea that increasing the thickness of the liner increases the stress relief,⁸ and this is supported by finite element analysis.⁸⁹

Using flowable composite as a liner has been advocated by many authors.^{8, 90,}⁹⁴ Flowable composite has many advantages: fewer voids inside the liner layer;⁹¹ easy application, and flexural strength. A highlight of the current study is the high flexural strength exhibited when the RC was lined with the flowable RC. It is heartening that a another recent study on the effect of flowable RCs on the strength of RCs also reported high bond strengths.⁹⁵ On the other hand, no other significant differences were observed (good or bad) between RCs restored with and without flowable liners.⁹⁶

SUMMARY AND CONCLUSIONS

The null hypothesis of this study was that the flexural strength of the monolayer resin composite is not different from that of a bilayer resin composite with a liner.

The hypothesis of this study was partially accepted, because high flexural strength was observed for both the unlined resin composite and the resin composite lined with the flowable composite.

- Thirty days in water significantly decreased flexural strength over that observed after 24 h in water for both the unlined resin composites and those lined with flowable composite.
- Time in water does not have a significant effect on the flexural strength for the resin composites lined with either of the resin-modified glass-ionomer cements.
- After 24 h and 30 d in water, the unlined resin composite and the resin composite lined with a flowable resin composite each had higher flexural strengths than did resin composite bars lined with either of the resin-modified glass-ionomers cements.

The factors that lead to early failures must be distinguished from those that occur through years of service. Longevity of dental restorations is dependent upon many different factors, including the type of material; the finishing techniques affecting the surface smoothness; the size and distribution of flaws; the patient's occlusion, habits, and oral hygiene, and dentist's clinical skill and knowledge.

APPENDIX

FLEXURAL STRENGTH CALCULATIONS AND TRANSFORMED BEAM THEORY

Flexural strength for the monolayer was calculated as follows:

The neutral surface (centroid) divides the specimen into two planes. The plane above the centroid will contract in length during bending, while the one below will expand in length during bending.^{73,74} For a monolayer beam, the centroid is calculated by the dividing the height of the beam by two.

$$c = h / 2 \quad \text{equation 1}$$

For the bilayer beam, the composite transformed method was used when the bilayer beam specimen of resin composite and liner was transformed into a uniform layer of resin composite by using the transformation factor n ,^{73,74}

$$n = \frac{E_l}{E_c} \quad \text{equation 2}$$

where E_c is the elastic modulus for composite and E_l is the elastic modulus of liner. The elastic moduli of the materials were determined by ultrasound technique (Table II). Resin composite/Vitrebond bilayer specimen is used here to show a flexural stress calculation using composite beam theory.

The transformation factor n is calculated as follows:

The elastic modulus of RC is 18.3 GPa, and for the Vitrebond, 10 GPa, so that $n = 10/18.3 = 0.547 = 0.55$.

The width for the RC is 1.5, and for the liner, 0.5, so that the transformed width of the liner is: $0.5 \times 0.55 = 0.275 \text{ mm} = 0.28$.

Thus the new transformed liner width = $1.5 + 0.28 = 1.78$ mm

The centroid for the transformed beam was calculated using the following formula:

$$c = \frac{t_{rc} + nt_L}{2} \quad \text{equation 3}$$

Where t_{rc} is the resin composite's thickness; t_L is the liner thickness, and n is the elastic modulus ratio for composite and liner.

The centroid is calculated using:

$$\text{equation 3} = \{ 1.5 + (0.5 \times 0.55) \} / 2 = 1.78 / 2 = 0.89 \text{ mm (Figure 12).}$$

Then, the flexural strength was calculated for both the monlayer and bilayer specimen using the following equations:

The flexural stress σ at the bottom of the beam is:

$$\sigma = \frac{Mc}{I} \quad \text{equation 4}$$

where M is the bending moment; c is the centroid; and I is the section moment of inertia. In terms of the load P and the span length L , the moment is:

$$M = \frac{PL}{4} \quad \text{equation 5}$$

And the moment of inertia I can be calculated from the width b and height of the beam:

$$I = \frac{1}{12} bh^3 \quad \text{equation 6}$$

Substituting I and M at the fracture load into equation 4 yields the fracture stress.

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ABSTRACT

FLEXURAL STRENGTH COMPARISON OF MONOLAYER
RESIN COMPOSITE TO BILAYER
RESIN/LINER COMPOSITE

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Clinical evidence suggests that the use of liners in posterior composite restorations may increase the frequency of restoration fractures. Materials that have been used as liner materials for resin composite (RC) restoration include conventional glass ionomers, resin-modified glass ionomers (RMGI), and flowable composites. The aim of this study was to compare the flexural strength of a monolayer of resin composite with that of a bilayer of resin composite and liner. Four types of RC beams were tested: a monolayer control that is an un-lined RC (Tetric EvoCeram, Ivoclar Vivadent) and three “bilayer” specimens that consisted of this same RC lined with one of three liners. The three liners used included two RMGI cements (Vitrebond LC liner; 3M ESPE and, GC Fuji Lining LC; GC America) and a flowable resin

composite (Tetric EvoFlow, Ivoclar Vivadent). Each group was tested after water storage for 24 h and 30 d. Altogether, eight, 12-specimen groups were fabricated and tested.

Methods: A 25 x 2 x 2 mm mold was completely filled with the RC to form the control beams. To form the bilayer beams, this mold was filled with 0.5 mm of the liner and then with 1.5 mm of the RC. Specimens were stored in 37°C distilled for either 24 h or 30 d. Immediately prior to testing, the 30-day groups were also thermocycled 2500 times, between water baths at 7°C and 48°C with a 30-s dwell time and a 10-s transit time.

Flexural strength was determined using a three-point-bending device. A two-way analysis of variance (ANOVA) with interactions was used to investigate how liner group (or no liner) and storage time affected strength.

Results: The interaction between liner type and storage time was significant ($p = 0.0128$). The un-lined RC (the monolayer beam) was significantly stronger after 24 h than after 30 d in water ($p = 0.0098$). Water storage between 24 h and 30 d did not change the flexural strength of any of the bilayer (lined) beams ($p > 0.05$). After storage for 24 h and also for storage for 30 d, both un-lined RC and RC lined with the flowable RC exhibited significantly higher flexural strength ($p = 0.0001$) than the bilayer beams lined with either RMGI liners.

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