

Resin modified glass-ionomers: Strength, cure depth and translucency

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Abstract

Background: According to the classification suggested by McLean, Wilson and Nicholson only three materials, currently marketed, fit the designation of resin modified glass-ionomers. These materials will undergo an acid/base setting reaction but also contain a limited quantity of a monomer that will polymerize as a result of irradiation. The quantity of polymer is limited to the extent that it will not interfere with the normal acid/base setting reaction and will therefore allow for the ion exchange adhesion with tooth structure that is typical of glass-ionomer. There is a third setting reaction incorporated to ensure remaining monomer, that is not affected by irradiation, will still polymerize. A series of experiments were carried out to determine the effect of the three types of setting reaction on the strength, depth of cure and translucency of these three materials.

Methods: Specimens, both with and without irradiation, were subjected to a shear punch strength test. To determine the depth of cure brought about through irradiation, specimens were tested immediately after construction according to the test in ISO – 4049 2000 (E). Translucency is clinically significant and will vary according to whether the material has been subjected to irradiation or cured through the acid/base reaction alone.

Results: The strength of all materials tested was higher in specimens subject to irradiation. The depth of cure was found to be both shade and irradiation time dependent. Irradiated specimens were found to be only marginally more translucent than those allowed to set without irradiation.

Conclusions: It was concluded that, for cavities more than 3mm deep, these materials should be placed incrementally to allow for a full irradiation initiated cure.

Key words: Resin modified glass-ionomer, shear punch strength, depth of cure, translucency.

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INTRODUCTION

The resin modified glass-ionomers have been defined as glass-ionomers that are modified by the inclusion of a resin monomer and set partly via an acid/base reaction and partly through photochemical polymerization.¹ However, there is a third setting reaction included so that any remaining monomer that has not set photo-chemically will undergo a chemical polymerization.² The materials were introduced, at least in part, to overcome the lack of stability in the water balance of the early versions of the glass-ionomers, that set through an acid/base reaction only, over the first few hours after placement.³

There are three materials in this category currently on the market (Table 1) and it has been suggested that there may be significant differences between the physical properties, strength, depth of cure and translucency in these materials following irradiation compared with specimens that have been allowed to undergo the acid/base setting reaction. They are stronger and show an improved translucency over the original glass-ionomer materials that set through an acid/base reaction alone although it is possible to obtain quite satisfactory aesthetic results with the latter following careful handling.⁴ As there could be clinical implications in the differences in physical properties developed by the three different setting reactions,⁵ a series of tests was carried out to identify the differences.

Hydroxyethyl methacrylate (HEMA) is the resin incorporated in all three materials and the amount added is in the vicinity of 15-20 per cent (by volume) of the liquid. Following mixing at a powder to liquid ratio of 3:1 or greater, there will be less than 5 per cent HEMA in the finished set material.⁶

Following placement, the top layer of a restoration will be irradiated for 20 seconds or more. Within the layer affected by the light there will be two setting reactions occurring simultaneously. From the start of mixing there will be the conventional acid/base reaction with the polyalkenoic acid attacking the surface of the glass particles and releasing calcium and aluminium ions to form the matrix. This component will be partly set within seven to 10 minutes but the water balance

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Table 1. Materials used

Product	Shade	Manufacturer	Batch number
Fuji II LC	A2	GC Corporation (Tokyo)	9094
	A3		2141
	A4		909292
	B2		220293
	C4		9906303
Vitremer	A3	3M Dental Products (USA)	20000808
Photac-Fil	A3	ESPE GmbH (Germany)	FW0064272

will still be unstable. Gelation is relatively slow and the reaction will continue for weeks or even months. In the resin modified glass-ionomers the acid/base reaction will initially be a little slower than it would have been in a conventional glass-ionomer because the HEMA has replaced some of the normal water content and water is an essential component of the acid/base reaction.⁷

At the same time, because of the incorporation of traces of camphorquinone and a tertiary amine in the formula, irradiation of the surface layer will initiate polymerization of the HEMA and this will be complete in less than one minute. This reaction is quite separate from the acid/base reaction but a high degree of cross linking will occur between the two matrices as the acid/base reaction continues. There will be a certain amount of shrinkage brought about as the polymer sets but, in view of the small amount present, shrinkage will be minimal and will be compensated over a short period through uptake of water from the oral environment.⁸

The depth of cure through irradiation will be limited by the depth of penetration of the light. However, there is a third polymerization setting reaction initiated through the incorporation of a "redox" catalyst system composed of micro-encapsulated potassium persulphate and ascorbic acid.¹ This is similar to the original setting mechanism used in the early composite resins and is incorporated to ensure that any HEMA, not polymerized through irradiation, will set. The acid/base reaction will take place relatively slowly when compared to light activation but it can be assumed that a similar cross linking will take place between the polymer and the finally set glass-ionomer. It is suggested that the three separate setting reactions, i.e., irradiation and the combined chemical cure reactions, will lead to the development of three materials that are similar but not identical.

There are two potential problems associated with the inclusion of a monomer into the glass-ionomer formula. Firstly, HEMA is highly hydrophilic and may lead to water uptake over time⁹ and this can cause expansion and a reduction in wear resistance. Secondly, there is a risk of phase separation in a situation like this where there are two polymeric matrices co-existing and this could lead to breakdown of the restoration.

It is apparent that the material on the surface layer that has set through light activation is relatively strong and translucent⁵ but there has been little study carried out on the material that has been allowed to cure

without irradiation at the base of a deeper restoration. The physical properties of this layer have not been previously reported. Bond strength of a glass-ionomer is directly related to the tensile strength of the cement because, as a result of the ion exchange reaction with the tooth structure, failure is always cohesive in the glass-ionomer rather than adhesive at the interface.¹⁰ Therefore if the underlying material, that has not been light activated, has low physical properties the adhesion will be compromised. There is also the possibility of modifying the translucency of the final restoration if the surface irradiated component is highly translucent and the subjacent material is less so.

A series of tests was conducted to determine the physical strength, the depth of cure and the translucency of specimens of the three resin modified glass-ionomers with one series being set by irradiation and the other series being allowed to cure without irradiation.

MATERIALS AND METHOD

Shear punch strength test

A series of specimens of the three materials listed in Table 1 was made in brass washers with an internal diameter of 8mm and approximately 0.8mm thick, following manufacturers instructions concerning mixing and light activation. The washers were placed in groups of four on a glass slab with a polyester strip under them. Glass microscope slides, 1mm thick, were placed on either side of the washers to act as spacers and the material was syringed into the washers. Another polyester strip was placed over the top of the washers and pressure was applied using a heavy glass slab. The top glass slab was then removed and the material subjected to irradiation through the polyester strip using a Visilux 2 (3M ESPE, Minnesota, USA) activator light. Each series of 10 specimens was polished in a small polishing machine (Minimet, Buchler Co, Illinois, USA) to ensure smooth parallel surfaces between 0.8 and 0.9mm thick.

The same system was used to prepare specimens that were kept free from light activation so that they could only set through the acid/base setting reaction and the chemical polymerization reaction. In this situation black plastic strips were substituted for the polyester strips thus ensuring the specimens were maintained without light for the maximum nine days of storage. All specimens in both series were stored in an airtight container over a water bath held at 23°C until such time as they were polished and subjected to the shear punch test.

Thirty specimens of each material were prepared as above for each of the test routines. Ten of the irradiated specimens were tested with a shear punch strength test after 24 hours, a further 10 at three days and the remainder at nine days. The specimens not submitted to irradiation were stored in the same manner and tested at similar intervals. The equipment used was a universal testing machine (Hounsfield, H50KM,

Hounsfield Test Equipment, Surrey, England) with a cross-head speed of 1.0mm/minute. The technique has been described in detail⁵ and the method has been shown to be useful in making comparisons between different materials and within the same material after variations in treatment.

Depth of cure

The requirements for this test are set out in ISO 4049-2000 (E). Specimens were constructed in a stand made to accept up to six specimens. Holes were drilled into a split mould sufficient to accept 10mm lengths of black plastic tube with an internal diameter of 4mm. Each length of plastic tube was split along its length to facilitate removal of the specimen after curing and placed into the mould. The appropriate material was syringed into the mould to the full depth, taking care to minimize the inclusion of voids and bubbles. A small excess was left on the top, a polyester strip was placed over and a glass slab applied to exert pressure and ensure adaptation of the material into the mould. The slab was removed and the top of the material irradiated through the polyester strip for the time recommended by the manufacturer. Shade A3 of all three materials, as well as Shade B2 and C4 of Fuji II LC, were subjected to a 20s irradiation time to test variation in depth of cure as related to colour.

Immediately following irradiation the specimens were removed from the mould and the excess uncured material, at the end distant from the light, carved off using a sharp blade. The length of the cured material was measured with a micrometer.

Specimens of Fuji II LC, Shade B2, were subjected to a 40s irradiation time to test the influence of extending the time of exposure to the activator light.

A further group of specimens was stored in an airtight container over a water bath and held at 23°C for one day before testing, at which time no unset material could be carved away.

Translucency testing

A series of 10 specimens of the same shade of each of the three materials was constructed in brass washers in the same manner as those that had been subjected to the shear punch strength test. Immediately following light activation all specimens were tested in the washers for translucency using a photometer (Photovolt, Model 502M, New York, New York, USA). The meter readings of the machine were standardized according to manufacturer's directions. The specimens were placed over the light aperture and the light beam applied briefly to record a reading. Specimens were then stored in water at 23°C and tested again after one hour, one day and one week using the same standard meter readings.

A second series of the same shade of the same three materials was allowed to cure without irradiation between black plastic strips for one week before being similarly tested.

Table 2. Shear punch strength (MPa) of the three materials following irradiation and after setting free of irradiation

	Day	Mean (MPa)	Standard error of the mean	Number
Irradiated				
Fuji II LC	1	62.6	2.9	10
	3	70.2	2.5	10
	9	68.9	2.2	10
Photac-Fil	1	58.9	1.5	10
	3	64.6	1.4	10
	9	68.0	1.6	10
Vitremmer	1	64.2	1.8	10
	3	67.5	3.2	4
	9	75.0	1.7	10
Non Irradiated				
Fuji II LC	1	36.9	1.6	10
	3	31.4	2.5	10
	9	47.2	1.9	10
Photac-Fil	1	51.2	2.1	10
	3	50.3	2.8	10
	9	56.1	2.9	10
Vitremmer	1	30.7	2.5	10
	3	33.3	5.8	4
	9	50.9	1.8	10

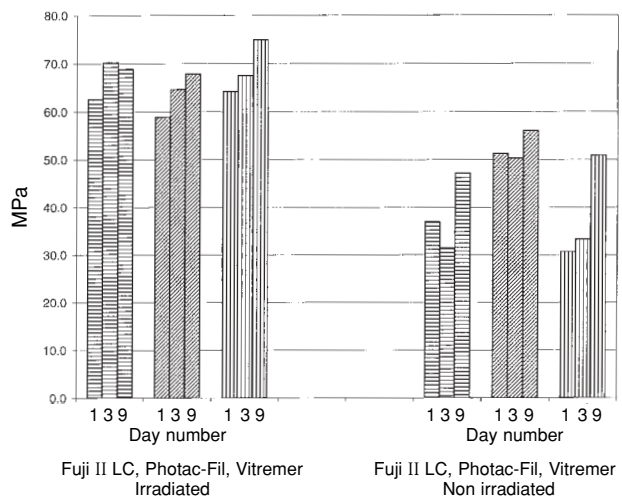


Fig 1. Shear punch strength of irradiated and non irradiated specimens at day one, three and nine.

RESULTS

Shear punch strength test

Table 2 and Fig 1 show the mean (MPa) values for the groups of specimens following light activation and the similar groups that were not irradiated, at one, three and nine days. The results were subjected to one-way analysis of variance with post-hoc paired comparisons using Scheffes test. The difference between the light activated specimens and those that were not irradiated was highly significant ($p < 0.01$).

When comparing the three materials at nine days following irradiation, Vitremmer was statistically stronger than Photac-fil ($p < 0.05$) but only marginally stronger than Fuji II LC. Comparing the strength of each of the three materials over the test period of one to nine days shows that both Vitremmer and Photac-fil had significantly higher strength ($p < 0.001$).

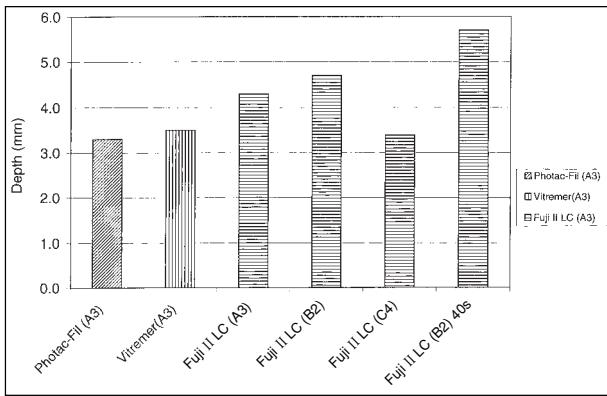


Fig 2. Depth of cure of each of the materials when tested immediately after irradiation.

Table 3. Depth of cure immediately after irradiation

	Colour	Mean (mm)	Standard error of the mean	Number
Fuji II LC	A3	4.3	0.1	10
Photac-Fil	A3	3.3	0.1	10
Vitremer	A3	3.5	0.1	10
Fuji II LC	B2	4.7	0.1	10
Fuji II LC	C4	3.4	0.1	10
Fuji II LC	B2(40s)	5.7	0.1	10

Without irradiation, Fuji II LC and Vitremer had a higher strength ($p < 0.005$) after nine days. Photacfil was stronger than both the others at each time period ($p < 0.05$) but showed only a small insignificant increase by day nine. In fact it had achieved over 90 per cent of its day nine strength within the first day after preparation.

Depth of cure

The results of the depth of cure test (Fig 2 and Table 3) were subjected to the same statistical analysis as used for the shear punch results. The depth of cure of Fuji II LC Shade A3 was significantly higher than that achieved with the same shade of both Photac-fil and Vitremer ($p < 0.001$). For the lighter shade B2 of Fuji II LC, extending the time of exposure to irradiation from 20 to 40s improved the depth of cure from 4.7 to 5.7mm ($p < 0.001$).

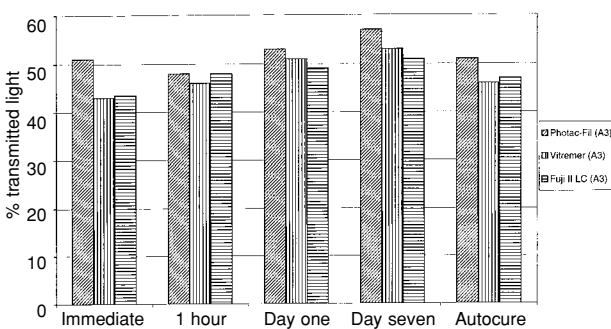


Fig 3. Translucency of the same shade of the three materials over time.

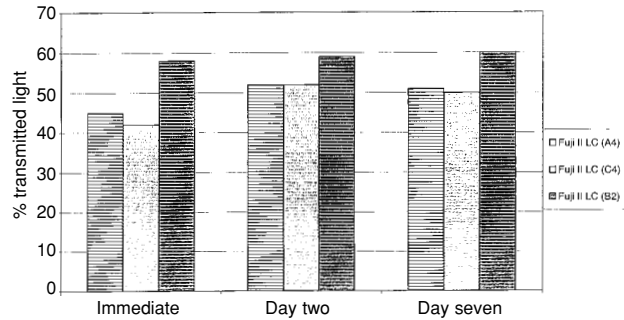


Fig 4. Translucency of three different shades of the same material.

Translucency

Figure 3 shows the steady improvement in the translucency of the three materials as they matured over the first week. Photacfil was consistently more translucent than the other materials immediately after placement but showed only a limited improvement over the next seven days. All three materials, when allowed to cure without irradiation, achieve a level of translucency between five to 15 per cent below that achieved following irradiation.

Figure 4 shows that the lighter shades are up to 20 per cent more translucent than the darker shades.

DISCUSSION

It has been pointed out^{2,4,8} that the setting reaction of all glass-ionomers is slow and prolonged and therefore a steady increase in strength can be anticipated for some months following placement. The present data tend to confirm these observations as they demonstrate a steady increase in strength in all three materials from one to nine days.

It is apparent that, after nine days, the specimens of all three materials that had been irradiated were 30 to 40 per cent stronger compared with those specimens not subjected to irradiation and this is clinically significant. At the end of the first day irradiated specimens of both Fuji II LC and Vitremer were 50 per cent stronger than specimens that had been allowed to cure through the acid/base setting reaction and at the end of nine days the difference was still substantial. Loss of a glass-ionomer restoration is the result of cohesive failure in the material. This means the stronger the material the greater the adhesion.¹⁰ In view of the markedly lower strength of materials that have been allowed to cure without irradiation, it is recommended that a restoration should be built in increments no greater than 3mm in depth. This technique will take advantage of the higher physical properties that can be developed through irradiation. Retention of the restoration will then not have to rely on the inner layers of the restoration, with lower physical properties, to provide the optimum level of adhesion.

The results shown in Fig 2 confirm the claims of manufacturers that the depth of cure, after 20s of irradiation, is at least 3mm for the darker shades, such

as A3 and C4, and will extend to more than 4mm for the lighter shades, e.g., B2. Extending the time of irradiation to 40s will increase the depth of cure to beyond 5mm for the lighter shades. This is likely to be clinically significant when placing large restorations in posterior teeth because of the probable depth of the cavity and the need for a darker shade of cement. There will be the added problem of placing the activator light in close proximity to the cavity. In these circumstances incremental buildup and increasing the time of exposure to the light become very important.

However, it should be noted that material that has not been irradiated will still set through the acid/base setting reaction even though the strength will be less. This means that the depth of cure is not as significant as it is for a resin composite restoration. A resin composite will set only to the depth of penetration of the light and material that has not been irradiated will not subsequently polymerize. Therefore, incremental buildup is critically important for resin composite because material that is not fully polymerized cannot be relied upon to provide adhesion to tooth structure or support for the restoration.

It has been assumed previously that there could be a significant difference in translucency between the resin modified glass-ionomer materials that had been set by irradiation and those that had not. There was a possibility that, in the presence of a significant loss of translucency, the translucency of the completed restoration would be compromised. Figure 3 shows that the loss of translucency of all three materials, when allowed to polymerize without irradiation, is in the range of five to 15 per cent so the aesthetic result will not be affected to a serious degree. The results also show that the lighter the shade of the material the greater the translucency.

CONCLUSIONS

The resin modified glass-ionomer materials that set by irradiation have some advantages over the original glass-ionomers that set through an acid/base reaction alone. The depth of cure is significantly higher than the average composite resin, that has been shown to be 2.0-2.5mm,¹¹ and the presence of the auto cure component is an added safety factor in development of adhesion in the depths of a deep cavity. However, in view of the fact that material that has not been irradiated is not as strong as that which has been irradiated, incremental

buildup of the restoration is recommended for any situation where the light source is further than 3mm from the floor of the cavity.

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