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Shear Bond Strength of Provisional Restoration Materials Repaired with Light-cured Resins

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Clinical Relevance

Specific repair resins should be chosen for certain provisional materials, since optimal bond strength can be achieved only when the repair resin has similar chemical components to those of the resin matrix (either methacrylate or bis-acryl) for the provisional restoration.

SUMMARY

This study evaluated the repair bond strengths of light-cured resins to provisional restoration materials with different chemical compositions and polymerization techniques. Fifty discs (10 mm in diameter and 1.5 mm thick) were fabricated for each provisional resin base material, including a self-cured methacrylate (Alike), self-cured bis-acrylate (Protemp 3 Garant), light-cured bis-acrylate (Revotek LC) and a heat-cured methacrylate (Namilon). All specimens were stored in distilled water at 37°C for seven days before undergoing repair with one of four light-cured resins, including AddOn, Revotek LC, Dyractflow and Unifast LC and a self-cured resin (Alike), according to the manufacturers' instructions, for a total of 200 specimens. After 24 hours of storage in 37°C water, the shear bond strengths were measured with a universal testing machine and fracture surfaces were examined under a stereomicroscope. Two-way ANOVA revealed that provisional resin-base material ($p<0.001$), repair material ($p<0.001$) and their interactions ($p<0.001$) significantly affected the repair strength. Tukey's multiple comparisons showed that the lowest bonding strengths were found in specimens of heat-cured methacrylate resin materials repaired with bis-acryl resins, with their failure modes primarily being of the adhe-

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sive type. The highest bond strengths were recorded when the provisional resin-base materials and repairing resins had similar chemical components and the failure modes tended to be of the cohesive type.

INTRODUCTION

Self-cured polymethyl methacrylate (PMMA) has been the standard for provisional materials for many years. It has good strength and good color stability for a few weeks, is easily repaired, and is inexpensive. However, self-cured PMMA has a high exothermic value, undergoes significant shrinkage and has a disagreeable odor.[1-2] Previous studies reported that the fabrication of provisional restorations with self-cured PMMA directly in the mouth might lead to problems of pulpal damage and marginal discrepancies.[3] Recently, composites have gained in popularity for making provisional restorations, because of their ease of manipulation, reportedly low polymerization shrinkage, minimum exothermal reactions and lack of an objectionable odor.[4-5] Most of these materials use bis-acryl resin, a hydrophobic material that is similar to bis-GMA, and they are mixed with an inorganic filler to reinforce their physical properties. Although research has shown that bis-acryl resin composites provide several advantages compared to PMMA as provisional restoration materials, some authors reported that these materials are problematic regarding repair.[6-7]

Repairing or relining provisional restorations is not an uncommon procedure during treatment. Fractures of provisional restorations may occur intraorally between appointments. Occasionally, repair is more desirable than refabrication in the interests of efficiency and substantial costs, since making a good provisional restoration with adequate quality to ensure a healthy, functional and esthetic dentition is a time-consuming task, even for experienced dentists.[8] Direct and indirect repair procedures have been published; some use the same parent material for provisional restorations or incorporate different materials made from PMMA, bis-acryl provisional resins and flowable resin composites.[9] Among these materials, the use of self-cured acrylic resins, allowing for simple and quick repair, is most popular. However, direct clinical repair procedures with PMMA can be technically challenging. These challenges include an unpleasant odor, significant shrinkage, short working times and a pronounced exothermic setting reaction. Moreover, residual methacrylate monomer used as repair or relining materials demonstrates cytotoxicity and potential allergenicity.[10-11]

With the advantages of adequate working time, a minimal odor and less polymerization shrinkage, light-cured resin materials have been applied to repair provisional restorations. Fox[12] used composites as an interproximal contact and marginal repair material for acrylic resin provisional restorations. Solow[13] incorporated a composite veneer into an acrylic resin provisional restoration to combine the esthetics of a microfill composite with the contour and marginal adaptation of an acrylic resin. Moreover, Dumbrigue[14] described a method for fabricating multiple-unit provisional restorations using a light-cured composite for the shell, a self-cured bis-acryl composite as the relining material and a flowable light-cured composite for improving marginal adaptation. Also, Bohnenkamp and Garcia[9] reported an alternative procedure for the direct intraoral repair of bis-acryl resin composite provisional restorations using a light-cured flowable resin composite and concluded that the repair was efficacious and accurate. However, the strength of this repair approach, in terms of its resistance to fracture, remains questionable.

Numerous brands of provisional resin materials are currently marketed. It would be impractical to test the suitable repair resins and the related surface treatment modalities for each single provisional resin material. For this reason, it was decided to use two types of resin matrix, methacrylate and bis-acryl, for provisional resins with different curing methods. The purpose of this *in vitro* study was to evaluate the bonding of light-cured repair resins to these provisional materials. The null hypothesis for this study was that the shear bond strength of the repaired provisional resin materials is not related to the similarity of the resin matrix between the provisional resin-base materials and the repair resins.

METHODS AND MATERIALS

The provisional restoration materials and repair resins used in this study are listed in Table 1. Standardized cylindrical aluminum molds (10 mm in diameter and 1.5 mm deep) filled with provisional resin materials were cured according to the manufacturers' instructions. Fifty specimens were fabricated for each provisional restoration material. The powder-liquid ratios for the self-cured (Alike) and heat-cured resins (Namilon), as recommended by the manufacturers, were 1.86 and 2.05 g/1 mL, respectively. The self-cured bis-acryl resins (Protemp 3 Garant) were dispensed via an auto-mixing cartridge system. The self-cured specimens (Alike and Protemp 3 Garant) were allowed to polymerize undisturbed for 15 minutes and were kept in air for one hour. The heat-cured specimens (Namilon) were cured in boiling water for 60 minutes, and the light-cured bis-acryl material (Revotek LC) specimens were polymerized with a visible light-curing unit (Triad 2000, Dentsply, New York, NY, USA) for one minute. The specimens were stored in distilled water at 37°C for seven days before the repair treatments.

Table 1: *Provisional Resin and Repair Materials Used in the Experiment*

Provisional Resin Base Material	**Type**	**Curing Mode**	**Major Components**	**Manufacturer**	**Batch #**
Alike	M	self-cured	Methyl methacrylate	GC America, Chicago, IL, USA	60658 (powder) 0203051 (liquid)
Protemp 3 Garant	B	self-cured	Bisphenol A polyethylene glycol diether dimethacrylate polymeric urethane dimethacrylate	3M ESPE AG Seefeld, Germany	127094
Revotek LC	B & M	light-cured	Urethane dimethacrylate multi-functional methacrylate	GC America	0207103
Namilon	M	heat-cured	Methyl methacrylate	Justi Products, American Tooth Industries, Oxnard, CA, USA	02385
Repair Resin Material					
Alike	M	self-cured	Methyl methacrylate	GC America	60658 (powder) 0203051 (liquid)
AddOn	B	light-cured	Dicyclopentyldimethylene diacrylate urethane dimethacrylate	3M ESPE AG	131167
Dyractflow	B	light-cured	N,N-Dimethyl aminoethyl methacrylate carboxylic acid modified macromonomers	Dentsply, Konstanz, Germany	0209051575
Revotek LC	B & M	light-cured	Urethane dimethacrylate multi-functional methacrylate	GC America	0207103
Unifast LC	M	light-cured	Methyl methacrylate	GC America	0105082 (powder) 0105082 (liquid)

B, bis-acryl; M, methacrylate

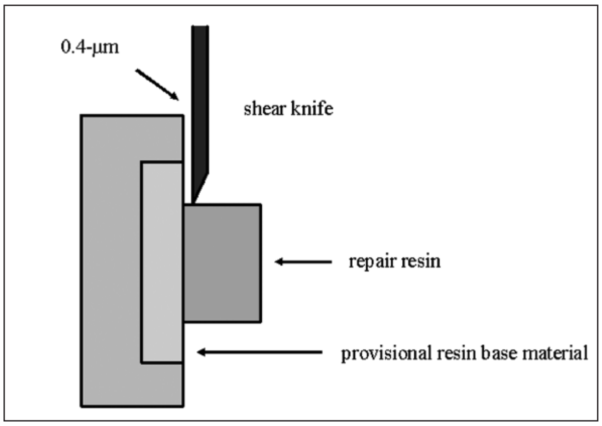

Figure 1. *Schematic drawing of the shear bond test setup.*

After water storage, the exposed surface of each resin specimen was ground flat with 180-grit silicon carbide paper, ultrasonically cleaned with distilled water and dried with compressed air. Then, self-adhesive masking tape with a central hole 6 mm in diameter was applied to the resin surface. The surfaces of the self-cured resin (Alike) were treated with its monomer for 15 seconds before repair began, and those of the heat-cured acrylic (Namilon) and light-cured bis-acryl resins (Revotek LC) were conditioned with the GC reline bonding agent according to the manufacturers' instructions. Size 3 hard transparent gelatin capsules (5.82 mm in diameter) were used as matrices for the production of columns of relining materials bonded to the provisional resin surface. The capsule was partially filled with one of the five relining materials to limit the thickness of the bonded material to 2 mm, then cured accordingly.

After the relining material had been polymerized, the gelatin capsules and masking tape were removed, and the specimens were stored in 37°C distilled water for seven days. The authors of the current study produced 10 specimens per group in each of the 20 reline resin-provisional material combinations. The specimens were then mounted in a special jig (Bencor Multi-T, Danville Engineering, San Ramon, CA, USA), and the shear bond strengths were determined using a universal testing machine (AGS-500G, Shimadzu Co, Tokyo, Japan) at a crosshead speed of 1.0 mm/minute by placing a knife-edged blade immediately adjacent and parallel to the adhesive interface between the repair resin and provisional material (Figure 1).

All statistical procedures were performed with SPSS 13.0 for Windows (SPSS, Chicago, IL, USA). The means and standard deviations of the shear bond strengths were calculated for each group. Data were analyzed by two-way analysis of variance (ANOVA) to determine whether there were any interactions between the reline resin and provisional materials, and further evaluation by one-way ANOVA and Tukey's multiple-comparison tests were conducted when appropriate. The significance level was set to $p<0.05$.

Table 2: *Mean Shear Bond Strength Values (SD) in MPa for Repaired Specimens*

	Reline Material				
Base Material	**Alike**	**AddOn**	**Dyractflow**	**Revotek LC**	**Unifast LC**
Alike	28.4 (4.0)^{ef}	10.4 (1.7)^{abc}	7.7 (2.7)^{ab}	12.3 (4.0)^{bcd}	25.7 (2.0)^{ef}
Protemp 3 Garant	7.9 (0.8)^{ab}	27.5 (3.1)^{ef}	25.6 (4.6)^{e}	9.1 (3.0)^{ab}	15.2 (2.4)^{cd}
Revotek LC	26.0 (3.6)^{ef}	30.3 (5.1)^{f}	27.4 (4.9)^{ef}	25.9 (1.8)^{ef}	25.7 (1.7)^{ef}
Namilon	15.5 (0.7)^{d}	6.1 (1.1)^{a}	7.3 (1.5)^{a}	7.6 (1.1)^{ab}	15.0 (2.4)^{cd}

The same letters indicate that values do not statistically differ (p>0.05).

Table 3: *Results of Two-way ANOVA*

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Base material	7165.302	3	2388.434	277.157	0.000
Repair material	1096.647	4	274.162	31.814	0.000
Base material * Repair material	6768.927	12	564.077	65.456	0.000
Error	1551.171	180	8.618		
Total	80128.171	200			

In addition, the interface, where failure occurred, was examined under a stereomicroscope (Sophia EX, Beldex, Tokyo, Japan) at a magnification of 10x. The nature of the failure was noted as either being adhesive, cohesive or mixed. Adhesive failure occurred when the area of the retained reline resin on the provisional base material was estimated to be <10% of the total bonded area. Cohesive failure was deemed to have occurred if >50% of the testing surface of the provisional base material had fractured.

RESULTS

Results of the shear bond strength testing for each experimental group are summarized in Table 2. Two-way ANOVA revealed that there were significant differences in bond strength because of the provisional resin base material variables, repair resin variables and their interaction ($p<0.001$, Table 3). Compared with the other repair resin-provisional material combinations, repaired heat-cured methacrylate (Namilon) exhibited a lower shear bond strength, especially when it was repaired with bis-acryl resins. Both methacrylate-based materials (Alike and Namilon) showed better bond strengths when they were repaired with methacrylate resins (Alike and Unifast LC), but the strengths significantly decreased when they were repaired with bis-acryl resin (AddOn and Dyractflow). On the contrary, bis-acryl-based Protemp 3 Garant had a high bond strength compared to bis-acryl repair resin (AddOn and Dyractflow), but it had poor bonding to methacrylate (Alike, Unifast LC). The Revotek LC provisional material exhibited significantly high mean values for all repair resins but did not show promising results when Revotek LC was used as the repair resin for the other provisional resins.

The specimens showed three types of failures: adhesive (interface), cohesive (only at the provisional resin base material) and mixed (interface and base material). The distribution of fracture modes on debonded specimen surfaces is shown in Table 4. Overall, repaired heat-cured methacrylate resin specimens were far more prone to adhesive and mixed failures, while specimens with similar resin compositions of base materials and repair resins showed mostly cohesive and mixed failures.

DISCUSSION

In the current study, the authors tested the bond strengths of different provisional resins repaired with commonly used repairing resins and considered the compatibility between the provisional materials and the repairing resins. Significant differences in shear strength were found between the experimental groups, depending on the provisional resin base and repair resin materials used. As the provisional base material, Revotek LC presented the highest repaired strength, while heat-cured Namilon resin revealed the worst results. There is no single repair resin that fits all provisional materials. As the interaction between the provisional material and repair resin was significant, the shear strengths of each repair resin to different provisional materials vary. Therefore, the null hypothesis was rejected.

The compatibility of bis-acryl and methacrylate provisional materials has seldom been tested.[15] However, several studies showed that heat-cured PMMA denture-base resin was better for use with MMA-based repair resin compared with non-MMA-based resin.[16-17] While Gregory and others[18] found that the repairs of resin composite with identical matrix chemistry did not produce bond strengths greater than those with a

Table 4: *Distribution of Fracture Modes on the Debonded Specimen Surface*

		Repair Material				
Base Material	**Type of Failure**	**Alike**	**AddOn**	**Dyractflow**	**Revotek LC**	**Unifast LC**
Alike	AD (%)	-	7 (80)	10 (100)	6 (60)	-
	MI (%)	-	3 (20)	-	3 (30)	-
	CO (%)	10 (100)	-	-	1 (10)	10 (100)
Protemp 3 Garant	AD (%)	8 (80)	-	-	9 (90)	6 (60)
	MI (%)	2(20)	-	1 (10)	1 (10)	3 (30)
	CO (%)	-	10 (100)	9 (90)	-	1 (10)
Revotek LC	AD (%)	-	-	-	-	-
	MI (%)	-	-	-	-	-
	CO (%)	10 (100)	10 (100)	10 (100)	10 (100)	10 (100)
Namilon	AD (%)	7 (70)	10(100)	10 (100)	10 (100)	8 (80)
	MI (%)	3 (30)	-	-	-	2 (20)
	CO (%)	-	-	-	-	-

AD, adhesive failure at the interface; MI, mixed fracture at the interface and base material; CO, cohesive fracture of the base material.

different matrix chemistry, Hagge and others[15] also demonstrated that the repair of bis-acryl composite provisional material with a flowable composite is effective and expedient.

In the current study, both self-cured (Alike) and heat-cured (Namilon) PMMA resins showed higher bond strengths with methacrylate-based repair resin, regardless of whether the curing mode of the repair resin was self-cured or light-cured. While the bis-acryl-based Protemp 3 Garant was efficiently repaired with its affiliated repair resin (AddOn) and a flowable compomer (Dyractflow), it was not compatible with the methacrylate-based repair resin. Moreover, Revotek LC, which possesses both bis-acryl and methacrylate components, exhibited significantly high mean values for all repair resins. According to these findings, it seems that provisional base and repair resins with similar chemical skeletons, bis-acryl or methacrylate, revealed high bonding strengths, while the repair strength was significantly reduced when the provisional base and repair resin were not similar.[19-20] However, it is also worth noting that there was no significant difference in repair strengths between bis-acryl resins with different matrix formulae. The finding is in agreement with the results of other studies.[15,18] However, further studies are needed to incorporate more materials to confirm this finding and to elucidate the mechanism.

Surface treatments before bonding are advocated by many researchers.[15-16,21-25] However, there is still no general rule that can be applied for all resin materials. Wetting the repair surfaces with methacrylate monomer has been used to soften PMMA.[23,26-27] Alternatively, chloroform, methylene chloride and acetone have been used as softening agents in resin repair.[16,25,28] Although the former two chemicals are effective in promoting the repair bond strength, they have also been proven to be biohazards with carcinogenic potential.[29] Therefore, the major components of GC reline bonding agent were changed to methacrylate and acetone, accordingly.[30] In the current study, the Namilon and Revotek LC specimens were conditioned with the GC reline bonding agent according to the manufacturers' instructions, and Alike was treated with methacrylate monomer for 15 seconds before the repair occurred. The optimal surface conditioning with methacrylate monomer for the denture-base resin has been thoroughly evaluated by previous research.[23,26-27] Vallittu and others[27] demonstrated that favorable results could be achieved by using the monomer treatment of heat-cured denture base for 180 seconds, compared with a shorter wetting time (0, 5, 60 seconds), while Olvera and DeRijk[31] showed that monomer treatment for four minutes was an optimal time for repairing a light-cured denture base. However, it is difficult to compare these data to the conditions the self-cured resin specimens (Alike) used in the current study. Since the treatment time is affected by the degree of conversion and molecular weight of the polymerized resin, self-cured resins with less-complete polymerization might require less conditioning time before repair. This matter should be further investigated.

Although Revotek LC showed high bond strength with all repair resins, it did not show promising results when used as a repair resin for other provisional resins. This can be attributed to the inherent high viscosity of this material, which may impair adaptation to the resin surface to be repaired. The importance of the viscosity of the repair resin was reported by Papacchini and others.[32] They found that the repair strength significantly decreased when the repair resin was cooled, and the interfacial adaptation and repair strength improved when the resin temperature was raised from 4°C to 37°C. Interestingly, the effect of the high viscosity of Revotek LC did not jeopardize the bond strength of the repair itself. This might denote that both the viscosity and chemical similarity of the repair resin are important considerations in polymer repair. Vallittu[33] also showed that self-cured PMMA of various powder-to-liquid ratios can be used to repair the fractured pieces of self-cured PMMA without affecting the strength of the repair.

Short-term interim coverage permits the autopolymerizing of provisional restorations, while prolonged placement involving periodontal prostheses and/or complete mouth rehabilitation usually requires the denser, more-esthetic heat-cured acrylic restorations. Compared to the self-cured methacrylate resin, the heat-cured provisional materials revealed lower repair strengths with various repair resins in the current study. This could have been due to fewer free carbon-carbon double bonds available on the heat-cured polymer for reaction with the repair resin.[10,34-35] A high degree of conversion that resulted from the use of heat polymerization improves the mechanical strength and hardness but also makes attaching the repair resin more difficult.

Analysis of the fracture sites showed that the failures of heat-cured PMMA specimens were primarily of the adhesive mode for most repair resins, while those of the self-cured PMMA specimens showed cohesive failure in specimens repaired with methacrylate-based resins and adhesive and mixed failure in specimens repaired with bis-acryl-based resins. On the contrary, Protemp 3 Garant specimens showed adhesive and mixed failure when they were repaired with methacrylate-based resins, and cohesive failure when they were repaired with bis-acryl-based resins. Revotek LC showed the greatest amount of cohesive failure among the provisional base materials for all repair resins, indicating that, overall, good bond strengths were achieved. In this study, as the bond strength increased, the proportion of cohesive failures increased as well.

In selecting a material for repairing or relining provisional restorations, several factors should be considered, such as bonding strengths, working time, setting time, handling properties, patient acceptance and material costs. Marginal refinement of provisional restorations with self-cured methacrylate resin is a common procedure in fixed prosthodontics. However, the malodor and tissue irritation of the monomer are always a concern. Previous studies showed that a significant amount of monomer is released after the self-cured resin is polymerized in a simulated oral condition.[10,36] Macintosh and Sutherland[37] also suggested that gingival trauma is minimized by eliminating intraoral use of the monomer. Moreover, the limited working time of the self-cured relining resin sometimes increases the difficulties of accurately catching the prepared margins of the abutment teeth by a less-experienced dentist, especially when multiple abutments are involved in long-span bridges. Although chilled monomer has been used to increase the working time, Chee and others.[38] found that the transverse strength of the restorative materials was significantly decreased by 17%. Using light-cured resin to refine the margins of provisional restorations not only provides sufficient working time but also eliminates the objectionable odor and tissue irritation of the monomer. Additional studies might concentrate on the use of light-cured relining resin specifically intended to evaluate the efficacy of marginal refinement of the provisional shell.

The current study has limitations, because only some selected materials for provisional restorations were evaluated and the study was entirely conducted *in vitro*. Laboratory tests do not simulate the many masticatory forces that provisional restorations are subjected to clinically, and test specimens do not simulate the actual provisional configurations. However, laboratory tests are helpful in comparing and evaluating the effects of different factors on the repair strengths of provisional resins. The results from the current study indicated that at least three factors might be involved in the repair bonding strength: the compatibility of the provisional base and repair resins, the viscosity of the repair resin and the residual monomer available on the provisional base resin. The importance of these factors and their interactions on resin repair deserve major attention in future research

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn.

1. No single repair resin is suitable for all provisional resins used in the study. The provisional base and repair resins with similar chemical skeletons, regardless of whether bis-acryl or methacrylate, showed high bonding strengths, while the repair strength was significantly reduced when the provisional base and repair resin were not similar.
2. The high viscosity of Revotek LC did not jeopardize the bond strength of the repair itself. However, when Revotek LC was used as the repair resin to different base materials, its viscosity may have certain effects on the repair strength.
3. For PMMA resin, heat-cured resin had lower repair strength compared with self-cured PMMA resin.

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