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Flexural Strength Evaluation of Immediate and Aged Repair of Provisional Restorative Materials

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Abstract

Purpose: To investigate the effects of different repair procedures on defects and fractures of provisional materials.

Materials and Methods: Three provisional restorative materials were selected: Jet, Integrity and Tuff-Temp Plus. Specimens (n=10) of each material were fabricated into 25 x 2 x 2 mm bars as non-repaired aged controls. Specimens were stored for 24 h in distilled water at 37˚C and then thermocycled for 500 cycles between 5-55˚C. For the aged repair group (n=10), one half (12.5 mm) piece of each broken specimen in the aged control group after three-point flexural test was repaired. Integrity and Tuff-Temp Plus were repaired with flowable resin; Jet samples were repaired with Jet acylic. For the immediate repair group (n=10), specimens of each material were fabricated in 12.5 x 2 x 2 mm bars and repaired immediately after curing to the full bar size using the same procedure above. The flexural strength at failure was assessed using an Instron universal machine (0.5mm/min crosshead speed). Data were analyzed with two-way and one-way ANOVA, and post-hoc Tukey comparisons to determine statistical significance ($p < 0.05$).

Results: For non-repair aged control group, the flexural strength (MPa) of Integrity (102.93±11.3) was significantly higher than Jet (85.10±5.7) and Tuff-Temp Plus, while Jet was higher than Tuff-Temp Plus (56.10±6.5). Both immediate (Jet, 60.74±7.9; Integrity, 68.44±9.1) and aged (Jet, 44.24±6.5; Integrity, 62.11±12.2) repair groups of Jet and Integrity showed a statistically significant reduction compared to their control groups. There was no significant difference in flexural strength among non-repair group and repair groups of Tuff-Temp. Immediate repair of Tuff-Temp Plus (61.56±7.1) and Jet (60.74±7.9) showed significantly greater flexural strength than aged repair (51.77±8.6; 44.24±6.5 respectively). There was no significant difference between repair groups for Integrity (immediate, 68.44±9.1; aged, 62.11±12.2).

Conclusions: Bis-acrylic provisional restorative materials of Integrity and Tuff-Temp had greater flexural strength than PMMA-based Jet after repair. Immediate and aged repair showed statistically significant reduction in flexural strength for Integrity and Jet compared to their non-repair groups, while Tuff-Temp Plus was lower but not affected by repair.

Keywords: Jet; Integrity; Tuff-Temp Plus; PMMA; Bis-acrylic composite; Thermocycling

Introduction

Provisional restorations are an integral part of fixed prosthodontics treatment during the period from tooth preparation to the placement of the definitive prosthesis, such as veneers, inlays, onlays, crowns, bridges, and implants [1]. To be successful, the provisional restoration should provide the following functions: (a) pulpal protection; (b) a diagnostic tool to analyze occlusion, tooth alignment, incisal/canine guidance, relationship between tooth and gingival tissue, and lip and tooth position; (c) maintain tooth position and prevent occlusal changes; (d) establish function, aesthetics and phonetics; (e) enable routine daily oral care; and (f) provide mechanical strength to support occlusal forces [1-3]. These characteristics of provisional restorations are essential to predict an optimal result in the definitive restoration [2].

Knowledge of the provisional material properties and pros and cons before use enables the selection of different provisional restorative materials to support the different clinical scenarios [4,5]. In general, provisional materials fall into two categories: acrylic-based resin and bis-acryl composite resin. Bis-acryl composite is further divided into two groups: bisphenol A-glycidyl methacrylate (bis-GMA) and urethane dimethacrylate (UDMA) [6]. Acrylic resins like Jet or ColdPac are relatively inexpensive, easy to handle, and have good polishability and margin adaptation. The major shortcomings are high shrinkage, heat generation during polymerization and low wear resistance. However, composite resin materials such as Integrity have some advantages over acrylic resin materials: less odor, less shrinkage, more resistant to wear, and better color stability. The drawback is that the composites are more expensive [7,8].

The most common complication with provisional restorations is the occurrence of defects during fabrication and/or fracture during service in the mouth between appointments. In provisional restoration fabrication, open or fractured margins, open or light interproximal contacts, and bad contour are often observed. In addition, provisional restoration fractures happen often in the cases of parafunctional habits or insufficient tooth reduction during preparation. Therefore, repairing provisional restorations is a big challenge to dentists. Based on the size and location of the defects, repairing may reduce chair time, cost, and increase clinic productivity compared to fabricating a new provisional restoration. However, it has been reported that the strength of repaired provisionals is significantly less than the strength of the original non-repaired interim crowns. For example, the bis-acryl materials demonstrate an 85% decrease in flexural strength after repair [9]. Thus, it is necessary to test the post-repair strength of provisional materials to determine whether it is advisable to repair the defects or fractures.

In this study, provisional materials selected were Jet acrylic resin, Integrity a bis-GMA composite and Tuff-Temp which is UDMA composite type. The purpose of this study was to investigate the effects of provisional restorative material types and repair techniques on the resistance of provisional materials to fracture and as a predictor of clinical performance. Three-point bending flexural test was used to measure flexural strength. The hypotheses were that there was no statistically significant difference in the flexural strength properties among the three provisional materials and that there was no statistically significant difference in the flexural strength of the materials with and without immediate and aged repairing.

Materials and Methods

The three provisional restorative materials selected for this study based upon monomer composition are described in Table 1.

Brand Name	Manufacturer	Material type	Shade	Lot Number
Tuff-Temp™ Plus	Pulpdent Corp, Watertown, MA	Rubberized-Urethane	A2	150313
Integrity	Dentsply, Milford, DE	Bis-Acryl	A2	150319
Jet	Lang Dental Manufacturing Company, Wheeling, IL	Methyl Methacrylate	62	P-382015AH L-380315AI

Specimen preparation

Non-repair group: Bar-shape specimens (n=10) of each material in shade A2 or 62(Jet) respectively were fabricated in the dimensions of 25 x 2 x 2 mm in accordance with the American National Standards Institute/American Dental Association specification # 27. All specimens were fabricated using a machined aluminum split mold (Figure. 1).

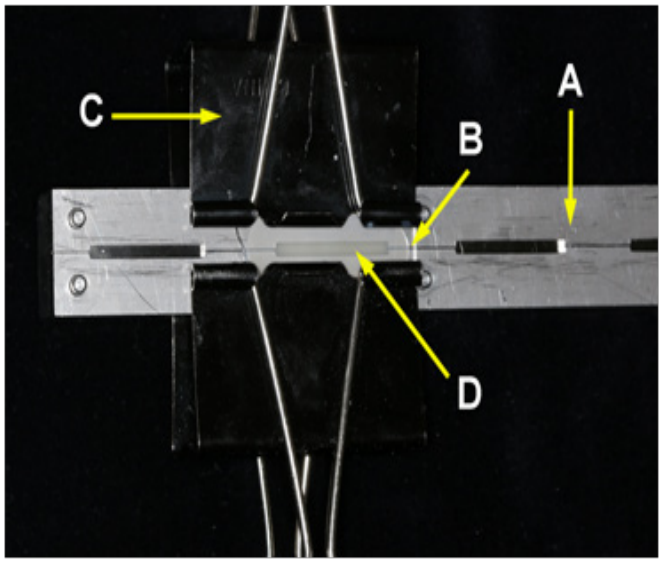

Figure 1. Specimen fabrication for non-repair group. A: mold; B: glass slide; C: clamp; D: sample.

For Tuff Temp and Integrity, a small amount of material was dispensed prior to specimen fabrication to ensure a homogenous mixture. The material was then dispensed directly into the mold from the mixing tip. For Jet, the powder and liquid were measured by volume according to the manufacturer's recommendation for the powder: liquid ratio of 3:2. The liquid was placed first in a resin-mixing cup and the powder added into the liquid. A stainless steel spatula was used to mix material and it was added into a syringe and injected into the mold to minimize porosity.

After each provisional material was used to fill the mold, the provisional material was covered with a mylar strip and a microscope glass slide. Each microscope slide was clamped to the aluminum mold to ensure stability and force out excess material (Figure. 2). The materials were allowed to self-cure in the mold for 15 minutes.

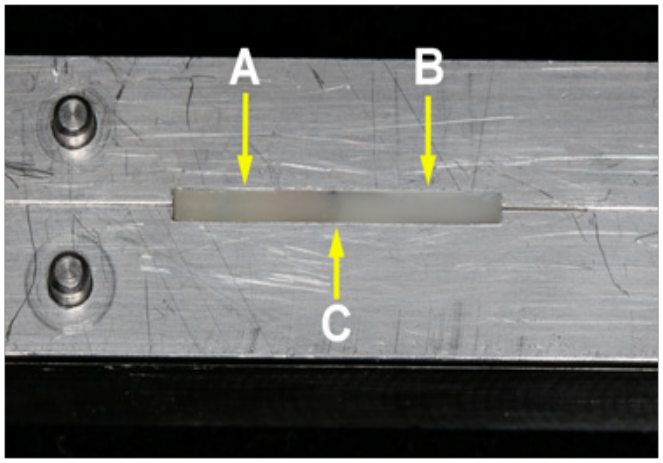

Figure 2. Specimen fabrication for aged repair groups.
A: broken part; B: repaired part; C: joint between two parts.

All specimens were polished with SiC paper (600 grit) to a standardized thickness of 2 mm, which was checked by a Digital Vernier Caliper (CD-6"ASX, Mitutoyo Corp). Specimens were stored in distilled water at a temperature of 37˚C for 24 hours in a dark jar and then thermocycled (Sabri Dental Enterprises) for 500 cycles between 5˚to 55˚C using 30-second dwell times in accordance with International Standards Organization Technical Specification (ISO/TS) 11405.

Aged repair group: To evaluate the effect of repair on aged specimens, the largest broken piece of each non-repair bar after 3-point flexural strength test was selected. The broken piece was cut to form a half-bar, 12.5mm× 2mm×2mm. The open end surface of the aged specimen was air abraded (MicroEtcher II, Danville Material) with 50-µm aluminum oxide for 3 seconds at a distance of 3 mm. Following air abrasion, the cut end surface of the half-bar (Tuff-Temp and Integrity) was treated with 35% phosphoric acid (Scotchbond®, 3M Dental Products) for 30 seconds and rinsed with water for 15 seconds. Specimens were returned to one end of the mold and treated with one layer of bonding agent (Scotchbond Universal, 3M Dental Products) followed by light curing for 20 seconds, and then repaired by inserting flowable composite resin (Revolution Formula 2, Shade C1, Kerr) into the open half-bar space followed by light curing for 40 seconds. The light tip was moved along the bar specimen (2 x 40 seconds) to cover the entire length of the repair bars. (Figure. 1) The intensity of the light (620mW/cm2) was checked every 10 specimens using an Efos Cure Rite radiometer (Efos Inc.) to ensure efficient light output.

For the traditional methacrylate resin (Jet) specimens, the exposed cut surface was treated similarly and the repair was done with Jet P/L mixture at 3:2 ratio. The material was allowed to self-cure in the mold for 15 minutes. All specimens were polished, stored and then tested following the same procedure as described previously for the non-repair group.

Immediate repair group

One half-length bar specimen (12.5 mm) was placed in the mold, and then the other half of the mold was filled with PVS material (AquasilMonophase, Dentsply) to be used as a template with the dimensions of 12.5 x 2 x 2 mm. (Figure. 3 I, II, and III)

This PVS template was placed to fill the half-space of the mold, and provisional material was injected into the other half-space against the PVS template. After the space was filled, the provisional material was covered with a mylar strip and a microscope slide. Each microscope slide was clamped to the aluminum mold to ensure stability and force out excess material. Each provisional material was allowed to self-cure in the mold for 15 minutes.After the half-bar of each material was made, the PVS template was removed. Then, the immediate repair was performed using the same procedure described for the aged repair groups. Those specimens were used to evaluate the effect of immediate repair on the provisional materials.

Flexural strength test

The flexural strength at failure was assessed using an Instron universal machine (Model 5560, Instron Corp.). The specimens were placed on the jig of a three point bending test with a span length of 20 mm and the load was applied on the middle point of bar specimens at a crosshead speed of 0.5mm/min until fracture occurred. For the repair group specimens, the load was applied at the middle point (also the repair joint) of bars until fracture occurred. The maximum load at fracture was recorded and the flexural strength was calculated according to the following formula:

$$S = 3PI/2BH^2$$

Where S is flexural strength, P is maximum load in Newton, I is distance between supporting rods, B is the width of the specimen, and H is the thickness of the specimen.

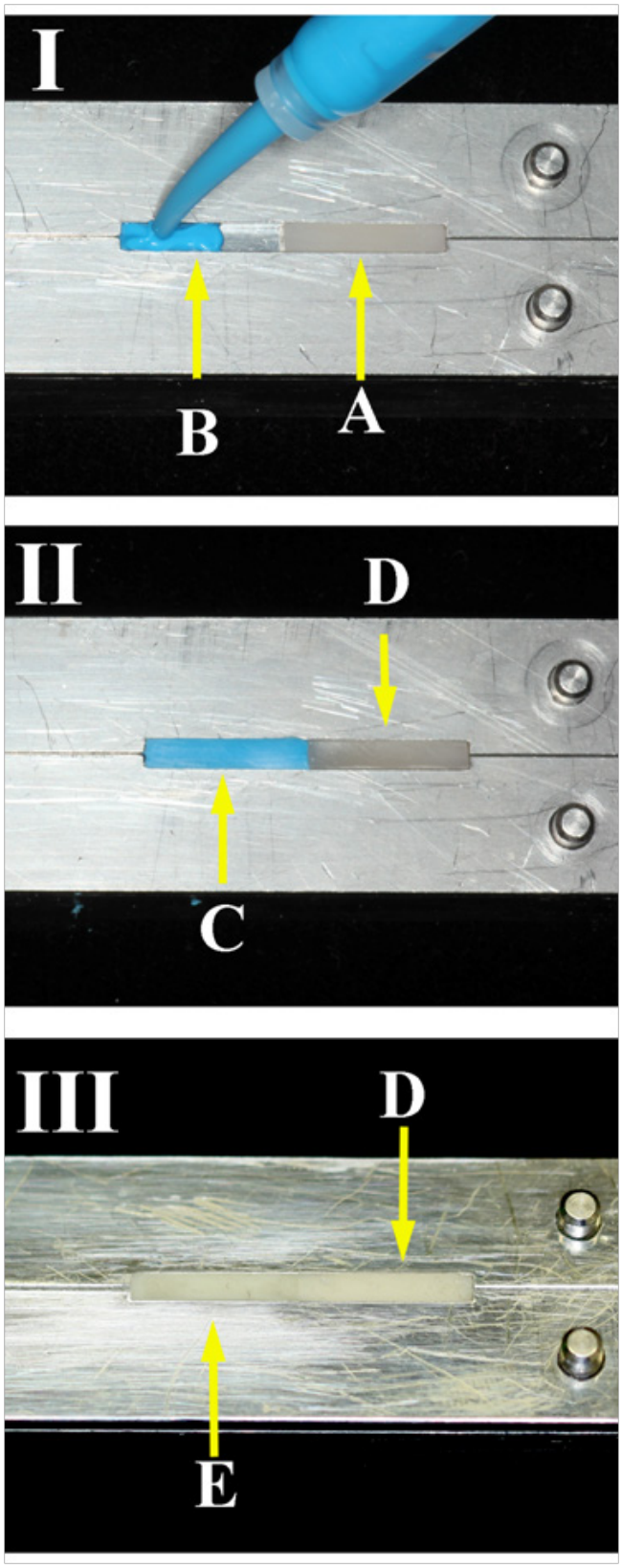

Figure 3. Specimen fabrication for immediate repair group. I: Fabrication of PVS template. A: prefabricated composite bar with the dimensions of 12.5×2×2 mm; B; injecting PVS material; II: Fabrication of a half-bars of provisional materials. C: PVS template with the dimensions of 12.5×2×2 mm; D: the fabricated half-bar of the sample, III: Immediate repairing. E: repaired half-bar.

Statistical analysis

The mean and standard deviation of the flexural 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 materials and the repair groups.For significant groups, further evaluation was done by one-way ANOVA and Tukey test for multiple comparisons. The significance level was set to $p<0.05$ for all tests.

Results

Table 2 shows the mean flexural strength and standard deviation values for each material and each treatment. Table 3 shows the two-way ANOVA Test results, which indicated that both material type and repair procedure significantly influenced the material flexural strength ($P< 0.01$).

	Non-Repair	Immediate Repair	Aged Repair
Integrity	102.93 (11.3)	68.44 (9.1)	62.11 (12.2)
Tuff-Temp™ Plus	56.10 (6.5)	61.56 (7.1)	51.77 (8.6)
Jet	85.10 (5.7)	60.74 (7.9)	44.24 (6.5)

Table 2: Mean (SD) values for flexural strength test in all groups.

Source	Sum of Squares	df	Mean Squares	F-Ratio	p Value
Repair	12568.992	2	6284.496	33.860	p<0.001
Material	3140.279	1	3140.279	16.919	p<0.001

Table 3: Results of Two-way ANOVA

As shown in Figure 4, the flexural strength of Integrity was sharply reduced by 30-40% after repair compared to the flexural strength without repair, while there was no statistically significant difference in flexural strength between aged repair and immediate repair groups of Integrity. In addition, there were no changes in flexural strength between repair and non-repair groups of Tuff-Temp, while flexural strength after immediate repair was greater than that after aged repair. For Jet acrylic, the flexural strength was significantly lower in repair groups than in non-repair group. Furthermore, aged repair group of Jet had weaker flexural strength compared to immediate repair group.

As shown in Figure 5, for non-repaired specimens, Integrity had the highest flexural strength, Tuff-Temp had the lowest flexural strength and Jet was in-between. In addition, the flexural strength of Integrity in the aged repair group was greater than that of Jet.

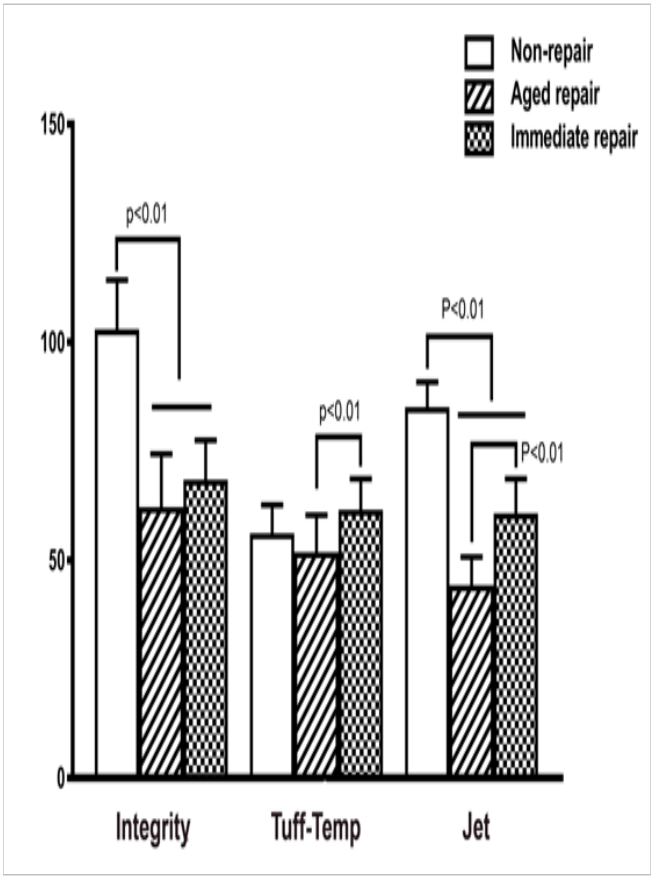

Figure 4. The effects of repair on flexural strength of three materials

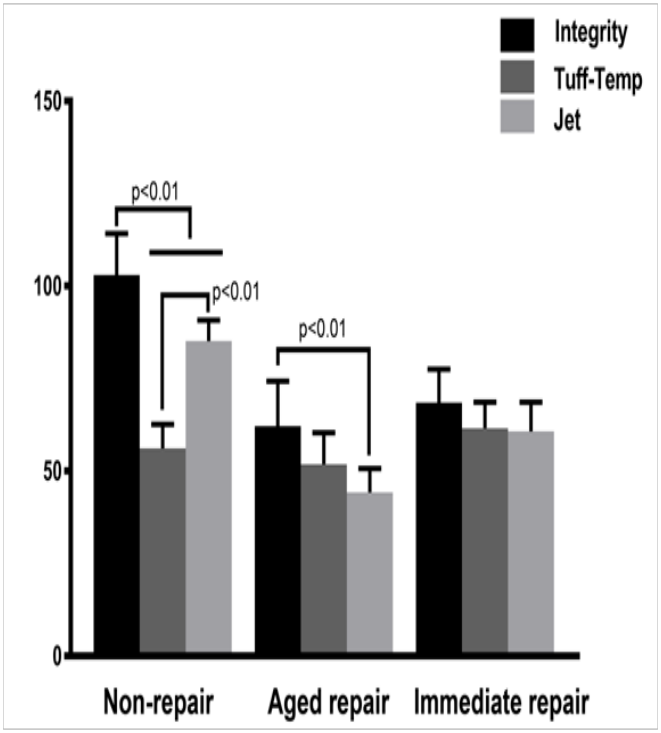

Figure 5. The effects of provisional material on flexural strength under different conditions

There were no statistical differences in flexural strength after aged repair procedure between Integrity and Tuff-Temp, as well as between Tuff-Temp and Jet. Furthermore, Integrity, Tuff-Temp and Jet had the same flexural strength after immediate repair, though there was a large difference in flexural strength than the aged non-repair condition.

Discussion

Mechanical strength is an important physical property for a provisional material to function in situ without failure. Chemical structures and components play an essential role on material properties [10-12]. Jet is a PMMA-based self-cure acrylic resin. PMMA has just one methacrylate group (monofunctional) in each monomer, which can form polymerization. There is minimal cross-linking in Jet. Integrity is a bis-acrylic material, which has two methacrylate groups (bifunctional) at each monomer. One group is used to form a polymer, the other to form cross-linking between monomers [10]. This property of bis-acrylic materials provides more flexural strength and resistance to fracture. Tuff-Temp is urethane dimethacrylate (UDMA), which is a bis-acrylic material. However, compared to BisGMA, there are no phenol rings in its monomer [13]. As a result, urethane dimethacrylate has higher flexibility. That is why UDMA is called rubberized-urethane resin. The present study showed that bis-acrylic-based Integrity had higher flexural strength than PMMA-based Jet, which may be due to the existence of more cross-linking in Integrity. In addition, because Tuff-Temp has no phenol rings, a greater flexural strength was observed with Integrity than Tuff-Temp. These results are in agreement with previous studies [14-20]. The present study showed that flexural strength for Tuff-Temp was lower than Jet, while the flexural strength for Integrity was higher than Jet, which indicated that the phenol rings in the chemical structure have a greater effect on material flexural strength than cross-linking, although it was reported that UDMA had more cross-linking than Bis-GMA [11]. In order to increase flexural strength and keep UDMA flexibility, some researchers have developed a partially aromatic urethane dimethacrylate [13]. Inorganic filler in composite has been shown to improve resistance to mastication forces and to fracture when filler loading reaches a certain threshold level [9, 21-23]. The fillers in Integrity lead to greater flexural strength than Jet which has no fillers. On the other hand, low molecular weight linear molecules in Jet may result in lower strength and less rigidity [15]. However, the results showed that the flexural strength of Tuff-Temp was lower than that of Jet, even though there are fillers in Tuff-Temp. This indicates that the chemical structures and groups are the decisive factors for material properties.

To investigate the repairability of provisional materials, a thermocycling device was used to simulate the conditions of clinical provisional restorative materials in the oral cavity. Based on the recommendation by ISO 11405:2003 for the study of biomaterial aging, provisional material was stored in water for 24 hours, and then thermocycled for 500 cycles. The 500 cycles mimicked 3-4 weeksof provisional material in the mouth [24]. There are two major techniques to test material repairability: flexural strength [9,17,19] and shear-bond strength [25-28]. Flexure strength was chosen because bending involves both tensile and compressive stress. This test is important for a provisional material used in long-span fixed prostheses, especially for patients with parafunctional habits such as bruxism or clenching and for patients wearing provisional restorations for an extended period of time. In the present study, both immediate and aged repair groups demonstrated significant reduction in flexural strength compared to their non-repaired aged groups, except for Tuff Temp Plus group. Integrity and Jet had 40% and 48% decrease in flexural strength after aged repair. The ISO 4049 has set 50 MegaPascals (MPa) as the minimum flexural strength for provisional restorative material when a bar of the material undergoes a 3-point bend test. All of the repair groups tested exceeded or came very close to this requirement, except for the repair of aged Jet (44.24±6.5 MPa). Therefore, it may be advisable to fabricate a new provisional restoration rather than repairing an aged provisional restoration of Jet. Koumjian and Nimmo [9] in 1990 demonstrated that bis-acryl provisional materials have poor repair property. They showed an 85% decrease in flexural strength after repair of a bis-acryl material. However, bis-acryl-based provisional materials have been improved with modified composition and improved filler technology over time [16]. In 2008, Balkenhol et al [29] reported that bis-acryl material (Protemp 3 Garant, 3M Dental Products) had better repair strength than the same brand of Protemp tested by Wang et al in 1989 [30]. Both of these studies used the same bis-acryl as a repair material and the surfaces were roughened using treated SiC sandpaper with 320 grit.

In addition, this study elucidated effects of material aging on repair. The results showed that the flexural strength of Jet with immediate repair was higher than that of aged repair, while there was no significant difference for Integrity and Tuff-Temp Plus. These results were consistent with earlier studies of Balkenhol et al. [25,29]. The flexural strength is controlled mainly by chemical bond formation between the original material and newly added repair material, which depends on unreacted C=C double bonds in cured resin materials [31]. Over time, the number of unreacted methacrylate groups in the materials decreases, which may compromise co-polymerization formation between aged material and resin monomers in the material used for repair [32]. A previous study showed that there may be more than 50% unreacted methacrylate groups to copolymerize with the newly added material in immediate repair [33]. Rinastiti et al [34] found that exposure of four different composite resin restorations to an oral biofilm for two weeks resulted in a statistically significant decrease in repair bond strength by more than 50%, compared to non-exposed samples. Generally speaking, the repair on aged restorations is less predictable than that on freshly fabricated provisional restorations.

Evidence has also shown that the water absorbed from saliva and other fluids into material affects material properties [33], which may result in surface degradation, softening of the resin matrix, loss of filler particles and chemical degradation of the resin itself [31,35]. To improve bond strength in both immediate repair and repair on aged material, various surface conditioning methods have been recommended, including mechanical and/or chemical treatments. Mechanical methods involve roughening the provisional resin surface with a diamond bur or air abrasion. It has been shown that surface roughening by aluminum oxide sandblasting increased composite repair strength more than roughening with a diamond bur [36]. Chemical approaches include the application of phosphoric acid and a variety of bonding resins. For PMMA-based materials like Jet, evidence showed that wetting the repair surfaces with methyl methacrylate monomer achieved optimum strength of an acrylic repair [37], In terms of bis-acryl composite provisional materials like Integrity and Tuff-Temp, Hagge et al [27] demonstrated that the repair of bis-acryl composite provisional materials with a flowable composite is effective and expedient. The general rule for repair is that using the materials with similar chemical properties to repair results in higher bond strengths than using the ones with different chemical properties [26].

In summary, the results demonstrated that provisional material type and aging both have an impact on material flexural strength, which further affects their clinical performance. From flexural strength point of view, bis-acrylic materials like Integrity and Tuff-Temp overall are superior to PMMA-based Jet. However, flexural strength is not the only criterion to select a provisional material. Other factors should be considered to meet different clinical scenarios, such as cost, working time, handling properties, polishability and esthetics.

Conclusions

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

- The non-repaired flexural strength of Integrity was the highest among three provisional materials, followed by non-repaired Jet and the Tuff-Temp Plus.
- Immediate and aged repair showed statistically significant decrease in flexural strength for Integrity and Jet compared to their non-repair groups; Tuff-Temp Plus was not affected by repair.
- Immediate repair of Tuff-Temp Plus and Jet showed significantly greater flexural strength than aged repair, but there was no significant difference between repair groups for Integrity.

Acknowledgment

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