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Original Article

Comparing the shear bond strength of direct and indirect composite inlays in relation to different surface conditioning and curing techniques

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ABSTRACT

Objective: The aim of this study was to test the null hypothesis that different surface conditioning (etch and rinse and self-etch) and curing techniques (light cure/dual cure) had no effect on the shear bond strength of direct and indirect composite inlays. **Materials and Methods:** A total of 112 extracted human molar teeth were horizontally sectioned and randomly divided into two groups according to restoration technique (direct and indirect restorations). Each group was further subdivided into seven subgroups ($n = 8$) according to bonding agent (etch and rinse adhesives Scotchbond multi-purpose plus, All-Bond 3, Adper Single Bond and Prime Bond NT; and self-etch adhesives Clearfil Liner Bond, Futurabond DC and G bond). Indirect composites were cemented to dentin surfaces using dual-curing luting cement. Shear bond strength of specimens was tested using a Universal Testing Machine. Two samples from each subgroup were evaluated under Scanning electron microscopy to see the failing modes. Data was analyzed using independent sample *t*-tests and Tukey's tests. **Results:** Surface conditioning and curing of bonding agents were all found to have significant effects on shear bond strength ($P < 0.05$) of both direct and indirect composite inlays. With direct restoration, etch and rinse systems and dual-cured bonding agents yielded higher bond strengths than indirect restoration, self-etch systems and light-cured bonding agents. **Conclusions:** The results of the present study indicated that direct restoration to be a more reliable method than indirect restoration. Although etch and rinse bonding systems showed higher shear bond strength to dentin than self-etch systems, both systems can be safely used for the adhesion of direct as well as indirect restorations.

Key words: Adhesive, bonding agent, dentin, shear bond strength

INTRODUCTION

Direct restoration is the most commonly used technique for both anterior and posterior teeth.[1] However, with direct restoration, excessive polymerization shrinkage increases the stress at the composite-tooth interface and can compromise the integrity of the bond.[2] In large posterior cavities, especially in those with cervical margins located in dentin, excessive shrinkage can produce marginal defects and gaps[3] that promote microleakage and result in marginal discoloration, post-operative sensitivity, secondary caries and pulpal irritation.[4] When some mistakes in placement and finishing are added to these material problems, resulting marginal leakage and poor anatomical form and proximal contacts can reduce restoration longevity.[5]

Recent developments in resin-based composite resins have made it possible to fabricate esthetic indirect adhesive restorations that aim to overcome the shortcomings of direct composite resin restorations, such as polymerization shrinkage and inadequate degree of conversion.[6] The high percentage by volume of inorganic fillers in indirect restorative material when compared with composite resins used in direct

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restorations results in improved mechanical and physical properties.[7] However, indirect restoration requires more dentin exposure than direct restoration and thus increases dentin sensitivity. Previous studies have shown the clinical performance of indirect composite restorations to be significantly affected by both the bonding of the luting agent to the tooth and the restorative material[6,8] and the surface treatment prior to bonding.[9,10]

In their systematic review of materials, Van Meerbeek *et al*.[11] classified dentin adhesive systems as either etch and rinse or self-etch systems. Whereas, etch and rinse systems require dentin to be acid-etched, rinsed and dried before the bonding agent is applied, self-etching bonding systems require no dentin pre-conditioning.[12,13] The simultaneous etching and resin infiltration that occurs with self-etching systems provides the important advantage of reduced technical sensitivity.

Whereas, Shortall *et al*.[14] reported indirect adhesive restoration to be a better alternative to direct composite restoration for larger cavities, Wakiaga *et al*.[15] reported no reliable evidence of either a direct or indirect type of veneer restoration being superior in terms of restoration longevity. However, recent advances in indirect restoration technology may improve the clinical life of indirect restorations over direct restorations. Manufacturers of new indirect composite restorative systems like Tescera ATL (Bisco Inc., Schaumburg, IL, USA) claim that these products show great success for occlusal restorations.

The aim of this study was to test the null hypothesis that restoration preparation technique (direct/indirect), surface conditioning (etch and rinse/self-etch) and curing of bonding agents (light cure/dual cure) had no effect on the retention strength of resin composite used with seven different adhesive systems.

MATERIALS AND METHODS

This study was conducted using 112 newly extracted non-carious, human molar teeth obtained according to protocols approved by the relevant institutional review board (Atatürk University Faculty of Dentistry). Tissue remnants and debris were removed and teeth were disinfected in 1% thymol and stored in distilled water until required for use. Specimens were decoronated and embedded in self-curing acrylic resin in 3 cm diameter teflon molds. Following polymerization, teeth were sectioned using a water-cooled saw (Struers Minitom, Struers, Copenhagen, Denmark) parallel to the occlusal surface to expose mild-coronal dentin. Standardized dentin surfaces were created by polishing specimens with waterproof polishing papers (#600, #800 #1200 SiC). Polished teeth were randomly divided into two groups according to restoration technique (direct restoration vs. indirect restoration) and subdivided into seven subgroups (*n* = 8) according to surface conditioning techniques used. Direct restorations were constructed using a hybrid resin composite Valux Plus (3M Dental Products, St Paul, MN, USA) and the indirect restorations were made using Tescera ATL system (BISCO Inc. Schaumburg, Illinois, USA) according to the manufacturers' recommendations.

Dentin bonding agents included four etch and rinse adhesives (Scotchbond multi-purpose plus [SBMP], All-Bond 3 [AB], Adper Single Bond [SB] and Prime Bond NT [PBNT]) and three self-etch adhesives (Clearfil Liner Bond [LB], Futurabond DC [DC], G bond [GB]). Of these, SBMP, SB and GB are polymerized by light-curing, whereas AB, PBNT, LB and DC are polymerized by dual-curing. Detailed information on bonding systems is given in Table 1.

Direct technique

Composite resin cylinders were built up on the dentin surfaces using a bonding jig (Ultradent Products Inc., South Jordon, UT and USA) and an incremental

Table 1: Bonding systems, surface conditioning, curing type and manufacturer

Bonding agent	Surface conditioning techniques	Curing mode	Manufacturer	Code
SBMP	Etch and rinse	Light-cure	3 M-ESPE, 3 M Corporate Headquarters, 3 M Center, St. Paul, MN, USA	SBMP
AB 3	Etch and rinse	Dual-cure	Bisco, Inc., 1100 W. Irving Park Rd., Schaumburg, IL, USA	AB
Adper SB	Etch and rinse	Light-cure	3 M-ESPE, 3 M Corporate Headquarters, 3 M Center, St. Paul, MN, USA	SB
PBNT	Etch and rinse	Dual-cure	Dentsply Caulk, Dentsply Int. Inc., Milford, DE, USA	PBNT
Clearfil LB 2 V	Self-etch	Dual-cure	Kuraray Medical Inc., Ote Center Building, 1-1-3, Otemachi, Chiyoda-ku, Tokyo, Japan	LB
Futurabond DC	Self-etch	Dual-cure	VOCO GmbH, Anton-Flettner-Straße 1-3 Cuxhaven, Germany	DC
GB	Self-etch	Light-cured	GC,3737 W. 127th Street, Alsip, IL, USA	GB

SBMP: Scotch bond multi-purpose plus, AB: All-bond, SB: Single bond, PBNT: Prime bond NT, LB: Liner bond, DC: Dual-cure, GB: G bond technique. Excess restorative material was carefully removed using a sharp explorer and the cylinders were cured for 20 s using a light-emitting diode unit (LED, Elipar Free Light II 3 M-ESPE, St. Paul, MN, USA) operated at 850 mW/cm^2.

Indirect technique

Composite resin cylinders were constructed in the same size with bonding jig's space used in direct technique. The specimens were light-cured and heat-cured using the Tescera ATL light box and heat box, respectively, in line with the manufacturer's recommendations. Following polymerization, cylinder surfaces were sandblasted with 50 µm aluminum oxide powders (Microetcher, Danville Engineering, San Ramon, CA) and rinsed with water.

Adhesives were applied on the dentine surfaces according to the manufacturers' instructions. Indirect cylinders were cemented to the dentin surfaces using dual-curing luting cement Duo-Link (Bisco Inc., Schaumburg, Illinois, USA) under a constant pressure of 5 kgf and then light-cured for 60 s using LED.

All specimens were stored for 24 h at 37°C and 100% relative humidity and then subjected to thermocycling (5/55°C, 1,000 cycles, 30 s dwell time). Shear bond-strength testing was performed using a Universal Testing Machine (Instron Corporation, Canton, MA, USA) at a crosshead speed of 0.5 mm/min. Maximum load to failure was recorded in Newtons and calculated in megapascals.

Fractured surfaces were examined under a stereomicroscope (SZ-TP Olympus, Japan) at ×20 magnification and failure modes were classified as either adhesive (failure at the dentin/composite interface), cohesive (failure within the resin composite or dentin) or mixed (partial adhesive/partial cohesive fracture). Furthermore, two samples from each subgroup were evaluated under scanning electron microscopy to see the failing surfaces [Figure 1].

Mean bond strengths for direct and indirect restorations were calculated for each subgroup ($n = 8$) and the data were pooled according to restoration technique (direct/indirect), surface conditioning (etch and rinse/self-etch) and curing of bonding agents (light cure/dual cure). Independent sample *t*-tests were used to compare mean bond strengths of pooled data according to restoration technique, surface conditioning and curing of bonding agents. ANOVA and Tukey's test were used to compare

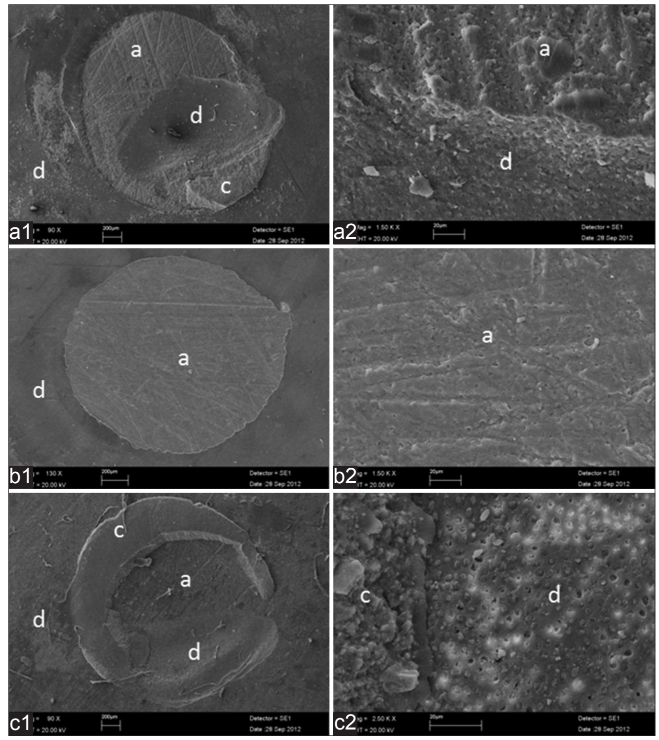

Figure 1: Scanning electron microscopy evaluation of dentin surfaces after shear testing: (a1, a2) ×90 and ×1500 magnification of a mix failing mode respectively in group indirect + All Bond 3; (b1, b2) ×130 and ×1500 magnification of an adhesive failing mode respectively in group direct + prime and bond NT; (c1, c2) ×90 and ×2500 magnification of a mix failing mode respectively in group indirect + Scotch bond multipurpose plus; a: Adhesive resin; d: Dentin; c: Composite resin

mean bond strengths of each dentin bonding agents; and the Chi-square test was used to analyze the distribution of fracture modes. All statistical analysis was conducted with the level of significance set at $P = 0.05$.

RESULTS

Mean shear bond strengths by restoration technique, surface conditioning and curing of bonding agents are given in Table 2. According to *t*-test, direct restorations were found to have significantly higher shear bond strengths than indirect restorations ($P < 0.05$); etch and rinse surface conditioning resulted in significantly higher shear bond strengths than self-etching ($P < 0.05$); and dual-cured bonding agents resulted in significantly higher shear bond strengths than light-cured bonding agents ($P < 0.05$).

Mean values of shear bond strength and standard deviations by restoration technique and bonding agent are given in Table 3. Mean values ranged from a high of 26.50 ± 6.05 MPa (direct restoration/PBNT) to a low of 16.96 ± 4.09 MPa (direct restoration/GB).

Table 2: Shear bond strength values (mean and standard deviation) of composite resin restorations by restoration technique, surface conditioning and curing of bonding agent

	Restoration technique		Surface conditioning		Curing of bonding agent	
	Direct	Indirect	Etch and rinse	Self-etch	Light-cure	Dual-cure
Shear bond strength (MPa)	23.47±4.80[a]	21.23±4.83[b]	23.35±4.63[a]	21.03±5.04[b]	21.08±4.76[a]	23.30±4.87[b]

The superscript letters represent significant differences in values for techniques. MPa: Megapascal

Table 3: Shear bond strength values (mean and standard deviation) for restoration technique (direct/indirect) and bonding agent

Bonding agent	Restoration techniques	
	Direct	Indirect
SBMP	26.32±2.2318[a]	22.93±2.53[abcde]
AB 3	24.96±2.55[abc]	19.29±1.87[cde]
Adper SB	22.90±4.11[abcde]	19.34±4.85[bcde]
PBNT	26.50±6.05[a]	24.54±5.58[abcd]
Clearfil LB 2 V	23.07±2.40[abcde]	18.31±1.75[cde]
Futurabond DC	23.64±4.70[abcde]	26.15±5.59[ab]
GB	16.9±4.09[e]	18.07±3.41[de]

The superscript letters represent significant differences in values for bonding agents. SBMP: Scotchbond multi-purpose plus, AB: All-bond, SB: Single bond, PBNT: Prime bond NT, LB: Liner bond, DC: Dual-cure, GB: G bond

For direct restorations, PBNT had the highest bond strength (26.50 ± 6.05 MPa) and GB had the lowest bond strength (16.96 ± 4.09 MPa). Bond strengths of PBNT, AB and SBMP were significantly higher than bond strengths of GB. No other significant differences in bond strengths were observed among the other subgroups for direct restorations.

For indirect restorations, DC had the highest bond strength (26.15 ± 5.59 MPa) and GB had the lowest bond strength (18.07 ± 3.41) and the difference between them was statistically significant ($P < 0.05$). Bond strength for DC was also significantly higher than for LB. No other significant differences in bond strengths were observed among the other sub-groups for indirect restorations.

Overall, direct restorations with SBMP and PBNT showed significantly higher mean shear bond strengths than indirect restorations with AB, SB, LB and GB and direct restorations with AB showed significantly higher mean shear bond strengths than both direct and indirect restorations with GB. Indirect restorations with PBNT also showed significantly higher mean shear bond strengths than direct restorations with GB.

The distribution of failure modes is presented in Table 4. For all groups, adhesive failure was the most common mode of fracture and no significant differences in fracture modes were observed among the groups ($P > 0.05$).

DISCUSSION

According to the findings of this study, the null hypothesis stating that the shear bond strength of composite resins is not affected by restoration preparation technique, surface conditioning or curing of the bonding agent must be rejected.

Adhesive dentistry involves the physical bonding of restorative materials to dental substrates in order to return esthetics and functioning to previously damaged teeth. Since the introduction of acid-etching into the field of dentistry,[16] various adhesive methods have been developed to bond composites to tooth structure. Given the importance of bond strength between the adhesive system and the dentin surface,[9] this subject continues to remain a topic of extensive research.

Studies have shown that indirect composite restorations, introduced in the 1990's, exhibit better clinical performance than direct restorations in terms of proximal contact, occlusal anatomy and marginal adaptation.[17,18] With indirect restorations, except for a thin layer of high-flow composite resin (so-called "resin cement") used to lute the restoration to the tooth surface, all technical processing of the restoration, including polymerization, is performed externally.[19] However, it is still possible for polymerization stress to occur during the curing of the resin cement, causing a disruption between the restoration and the cavity walls that will subsequently lead to marginal leakage, particularly if the margins are located in dentin.[20,21]

Douglas *et al*.[20] concluded that the indirect method of placement of composite restorations offers considerable improvement in microleakage performance, particularly on the dentin-restorative interface. However, our finding that direct restoration produces higher shear bond strengths than indirect restoration is in conflict with Douglas *et al*., given that microleakage is directly related to the strength of the bond between the dentin surface and the adhesive system/resin cement.

In clinical practice, indirect restorations are usually applied in large cavities. Thus, the clinical life of

Table 4: Failure modes of bonding agents for direct and indirect restorations

Bonding agents	Direct			Indirect		
	Adhesive	Cohesive	Mixed	Adhesive	Cohesive	Mixed
SBMP	6	-	2	5	1	2
AB 3	7	-	1	5	-	3
Adper SB	6	-	2	6	-	2
PB NT	7	-	1	5	1	2
Clearfil LB 2 V	6	-	2	5	-	3
Futurabond DC	8	-	-	6	1	1
GB	7	-	1	7	-	1

No statistically significant differences were observed among the groups. SBMP: Scotch bond multi-purpose plus, AB: All-bond, SB: Single bond, PBNT: Prime bond NT, LB: Liner bond, DC: Dual-cure, GB: G bond

indirect restoration can be affected by the physical properties of the restorative material. In the present study, indirect restorations were produced using the Tescera ATL system, according to its manufacturers, which offers improvements in terms of durability and appearance.

The present study found that the surface conditioning had a significant effect on the shear bond strength of resin composite to dentin, etch and rinse adhesives exhibited higher bond strength than self-etch adhesives. This finding is in line with a previous study that showed etch and rinse systems resulted in higher bond strengths than self-etch systems,[22] but conflicts with other studies that showed no differences between self-etch and total-etch adhesives in terms of bonding to dentin.[23,24] In our study, the bond strength of direct restorations was significantly lower when GB was used as an adhesive in comparison to all the other adhesives tested. These findings may be due to the adhesives' content and the surface-etching technique of the bonding systems.

It is possible that dual-cure bonding systems can significantly increase the retention of indirect restorations. The present study found dual-cure bonding agents to have higher shear bond strength than light-cure bonding systems. This is in line with previous studies that showed both dual-cure bonding agents and light-cured bonding agents have sufficient bond strength to tooth structures.[25,26] Further investigation is needed into the various adhesive methods used to lute indirect restorations as there seems to be no current consensus in the literature regarding which technique can best improve adhesive strength.[27]

In terms of failure mode, the present study found the majority of failures to be adhesive failures at the resin cement-restoration interface. In contrast to a recent study[28] that found a higher rate of adhesive failures at the resin cement/veneer interface for indirect restorations, our study showed no differences in failure modes between direct and indirect restorations.

CONCLUSIONS

Despite improvements in adhesive technology used for luting indirect restorations, the results of the present study indicated direct restoration to be a more reliable method than indirect restoration. Although etch and rinse bonding systems showed higher shear bond strength to dentin than self-etch systems, both systems can be safely used for the adhesion of direct as well as indirect restorations.

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