Effect of Light Curing Unit and Adhesive System on the Durability of Resin Composite Restorations

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Abstract: Objectives: To evaluate the microtensile bond strength of two different adhesives when cured with three different curing units. **Materials and Methods:** Scotchbond Universal Total-Etch Adhesive (SU) and Adper Easy Bond Self-Etch Adhesive (EB) [3M/ESPE] were used in this study. Occlusal surfaces of 18 human third molars were sectioned to obtain a flat dentin surface. The teeth were randomly assigned into 2 groups (n=9) according to the tested adhesive. Both adhesives were applied on the flat dentin surfaces according to manufacturer's instructions. Each group was further divided into 3 subgroups (n=3) according to the curing units that were used to polymerize the adhesive systems and the resin composite: 1) cured with halogen light curing unit, (PRO-DEN systems, Inc.- North Lombard street-Portland, USA); 2) cured with Elipar S10 unit (3M/ESPE); and 3) cured with Bluephaseunit (Ivoclar Vivadent). Composite resin (Feltik Z350 XT, 3M/ESPE) block was built up on each bonding surface by the incremental technique. After 24 hours distilled water storage at 37°C, the bonded specimens were sectioned vertically through the resin composite parallel to their long axis in mesiodistal and linguolabial directions forming 0.8mm^2 sticks for microtensile bond testing. Lloyd universal testing machine was used to test microtensile bond strength at crosshead speed of 0.5 mm/minute. The data were tabulated and statistically analyzed using Two-way Analysis of Variance (ANOVA) and Bonferroni's post-hoc test ($P \leq 0.05$). **Results:** Regardless of the tested curing unit, Scotchbond Universal adhesive showed statistically significantly higher mean microtensile bond strength (39.7 MPa). Meanwhile, both adhesives cured with Bluephase unit showed highest mean microtensile bond strength values (43.96 MPa). **Conclusions:** under the test conditions, Adper Easy Bond adhesive showed decreased bond strength when cured with either Elipar S10 or Bluephase. Curing with Bluephase improved microtensile bond strength of both tested adhesives.

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1. Introduction:

The rapid change and evolution in the adhesive dentistry resulted in an increase in the durability of the resin composite restorations. However, the creation of an effective and long lasting dentin bonding is considered a challenge than enamel bonding[1]. There are two approaches used to make efficient dentin bonding: etch-and-rinse and self-etching[2]. In etch and rinse technique, dentin surfaces are acid conditioned and the acid is rinsed in order to create partial demineralization of the dentin thus exposing the collagen fibrils[3]. Proper infiltration of the adhesive monomers around the exposed collagen and minerals necessitates the presence of moisture on the dentin surface to support the collagen fibers in order to generate adequate hybrid-resin reinforced layer. Determining the proper moisture content of dentin is considered a challenge[1], since, over wetting of etched dentin jeopardizes the dentin/adhesive bond strength.

On the other hand, although one-step adhesives merge all the bonding steps into one application step[4,5] and eliminates the concerns regarding residual dentin moisture[1], their long-term bonding effectiveness remains questionable[6]. Some studies showed degradation of the adhesive and the collagen fibers, which were not completely infiltrated, initiated by the water content in the underlying dentin[7-9]. Nevertheless, bond strength studies report conflicting results when the adhesive is bonded to dentine[10].

The selection of an efficient light curing unit (LCU) is critical factor for the bonded resin restorations. Since, the LCU should provide adequate degree of conversion for both the adhesive and resin composite[11]. Consequently, the material's physical and mechanical properties, such as ultimate bond strength to dental substratesmay be improved[12-14]. Resincomposites and adhesives have been usually cured with halogen light sources with a light intensity of approximately 400 mW/cm^2. These light curing units generate light through a thin tungsten filament at high temperatures producing a broad spectrum of wavelengths[15, 16]. However, these light-curing devices suffer from light degradation[17].

More recently, with the increased tendency to lessen the clinical times and to accomplish adequate polymerization, higher intensity light sources have been introduced to the market[18]. These new light sources including LED units have a light intensity up to 1200 mW/cm^2. However, increasing the light intensity doesn't mean that sufficient polymerization will be obtained[19]. Insufficient polymerization can result in reduction in the bonding efficiency of the resin composites to the tooth structure with consequent restoration failures.

Moreover, with the increase in the light intensity, some characteristics of resin composites such as contraction will be increased[20]. This polymerization-induced contraction which is dependent on the degree of conversion can result intensile and/or shear stresses at the tooth-restoration interface[21] with consequent decrease in the bonding of the resin composite to the cavity walls, leading to leakage at the tooth/restoration interface. Some studies compared LEDs with halogen light and reported that, LEDs present either similar or inferior results[22]. Meanwhile, other studies showed that current LED curing units can replace, in most situations, the conventional halogen light units[23, 24]. Therefore, these units need to undergo more laboratory testing.

The aim of this study is to evaluate the microtensile bond strength (µTBS) of two different adhesives when cured with three different curing units. The null hypotheses of this research are that, (1) etch and rinse adhesives achieve higher bond strength values than self-etch adhesive regardless of the used curing unit, and (2) the bonding effectiveness to dentine will not be affected by the curing units.

2. Materials and Methods:

Preparation of samples:

A total of 18 freshly extracted sound human third molars were collected after the patients' informed consent was obtained under a protocol reviewed and approved by the Ethical Research Committee, Faculty of Dentistry, King Abdulaziz University, Saudi Arabia. Extracted teeth were thoroughly cleaned using brushes and curettes and were stored in 1%chloramine solution at room temperature for one month until use[2]. Each tooth was embedded in an acrylic resin up to cement-enamel junction (CEJ) using a special designed mould. Dimension of the mould was 20 mm width x 20 mm length x 15mm height.

The occlusal third of the crown of each tooth was removed by sectioning the crown perpendicular to its long axis using a low speed diamond saw (Buehler- Isomat, Lake Bulff, IL, USA) under water coolant. The exposed dentin were finished using 600 Grit silicon carbide papers (Soft Flex, Germany) for 60 second sunder copious amount of water to create a uniform, clinically relevant smear layer. The teeth were then rinsed, dried and the exposed dentin surfaces were inspected under a stereomicroscope to ensure removal of all enamel remnants.

Grouping of the specimens:

The teeth were randomly divided into two groups (n=9) according to the tested adhesives (table 1):

Group one using Scotchbond Universal Total-Etch Adhesive (SU) (3M/ESPE),

Group two usingAdper Easy Bond Self-Etch Adhesive (EB) (3M/ESPE).

Table 1: Compositions and manufacturers of the testedmaterials.

Materials	**Principal components**	**Manufacturer**
Scotchbond Universal Total-Etch Adhesive	**Scotchbond Universal adhesive etchant:** 32% phosphoric acid by weight **Scotchbond Universal Adhesive:** Vitrebond Copolymer, methacryloxydecyl phosphate (MDP), **s**ilane and ethanol/water-based solvent system	3M/ ESPE, St. Paul, MN, USA.
Adper Easy Bond Self-Etch Adhesive	2-hydroxyethyl methacryate (HEMA), Bis-GMA, methacrylated phosphoric esters, 1,6 hexanedioldimethacrylates, methacrylate functionalized Polyalkenoic acid (Vitrebond Copolymer), finely dispersed bonded silica filler with 7 nm primary particle size, ethanol, water, initiators based on camphorquinone and stabilizers	3M/ ESPE, St. Paul, MN, USA.
Filtek Z350 XT (Universal Restorative)	**The resins:** Bis-GMA, UDMA, TEGDMA, and bis-EMA (6) resins. **The fillers:** 78.5% by weight a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles). An average cluster particle size of 0.6 to 10 microns.	3M/ ESPE, St. Paul, MN, USA.

Each group then subdivided into three subgroups (n=3) according to the curing units that were used to polymerize the adhesive systems and the resin composite:

1) Cured with halogen light curing unit, (PRO-DEN systems, Inc.-North Lombard street-Portland, USA);

2) Cured with Elipar S10 unit (3M/ESPE St Paul, MN., USA); and

3) Cured with Bluephase unit (Ivoclar Vivadent, Schaan, Liechtenstein).

Scheme of the work:

In the first group, the flat dentin surfaces of the teeth were etched using Scotchbond Universal adhesive etchant before applying the adhesive (SU). Whereas, in the second group, the self-etch adhesive (EB) was applied directly on the flat dentin surfaces without previous etching. Both tested adhesives were applied according to the manufacturer's instructions and cured with the assigned light curing unit. Composite resin (Feltik Z350 XT) block approximately 4 mm in height was built up on each treated dentin surface by using the incremental technique.

For the blocks of each subgroup, each composite increment was light cured for 40 seconds using the assigned light curing unit[25]. The light guide was held perpendicularly and within 1 mm of the surface[25]. Light intensity output was monitored throughout the experiment using visible curing light meter (SDS Demetron, Orange, CA., USA) to ensure a constant value of 600 mW/cm^2. After 24 hours distilled water storage at 37°C, the samples were sectioned vertically through the resin composite parallel to their long axis in mesiodistal and linguolabial directions in order to form 0.8mm^2 sticks for microtensile bond testing.

Six central sticks were randomly chosen from each specimen forming a total of 18 sticks per each subgroup. Each stick was placed in the universal testing machine (Model LRXplus; Lloyd Instruments Ltd., Fareham, UK) in which its ends were glued with cyanoacrylate adhesive (Loctite Super Bond Gel; Henkel, Dusseldorf, Germany) to specially designed metal plates (Fig.1). Then the tensile load was applied at a crosshead speed of 0.5 mm/minute, until the composite separated from the dentin. The load at the point of failure was recorded and microtensile bond strength (µTBS) values were expressed in MPa.

Statistical analysis:

Data were presented as mean and standard deviation (SD) values. Data were explored for normality by checking data distribution, histograms, calculating mean and median values and finally using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Microtensile bond strength data showed parametric distribution; so Two-way Analysis of Variance (ANOVA) was used in testing significance for the effect of adhesive system, curing unit and their interactions on mean microtensile bond strength. Bonferroni's post-hoc test was used for pair-wise comparison between the groups when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM (IBM Corporation, NY, USA.) SPSS (SPSS, Inc., an IBM Company) Statistics Version 20 for Windows.

Fig.1: A stick placed in the universal testing machine

3. Results:

The results of this study showed that the type of the adhesive, the curing unit, and the interaction between the two variables had a statistically significant effect on the microtensile bond strength ($P \leq 0.05$).

Effect of the adhesive system:

Regardless of the used curing unit; Scotchbond Universal adhesive system showed statistically significantly higher mean microtensile bond strength than Adper Easy Bond, as shown in table (2).

However, table (3) showed that, by using Halogen curing unit, there was no statistically significant difference between mean microtensile bond strength of the two adhesive systems. While using Elipar S10 as well as Bluephase curing units; Scotchbond Universal adhesive system showed statistically significantly higher mean microtensile bond strength than Adper Easy Bond.

Table (2): Descriptive statistics and results of comparison between microtensile bond strength values of the two tested adhesive systems regardless of curing unit

Scotchbond Universal	Adper Easy Bond	*P*-value
Mean ± SD	Mean ± SD	
39.7 ± 5.4	36.5 ± 3.9	<0.001*

**: Significant at $P \leq 0.05$*

Table (3): Descriptive statistics and results of comparison between microtensile bond strength values of the tested adhesive systems with each curing unit

Curing unit	Scotchbond Universal	Adper Easy Bond	*P*-value
	Mean ± SD	Mean ± SD	
Halogen	33.9 ± 1.1	33.8 ± 1.1	0.888
Elipar S10	39.0 ± 1.2	34.2 ± 1.5	<0.001*
Bluephase	46.3 ± 1.1	41.6 ± 1.4	<0.001*

**: Significant at $P \leq 0.05$*

Effect of curing unit:

Regardless of the tested adhesive system; Blue phase curing unit showed the statistically significantly highest mean microtensile bond strength. While, Elipar S10 curing unit showed statistically significantly lower mean microtensile bond strength. Halogen curing unit showed the statistically significantly lowest mean microtensile bond strength (Table 4 and Fig. 2).

Table (4): Descriptive statistics and results of comparison between microtensile bond strength values with different curing units regardless of adhesive system

Halogen	Elipar S10	Bluephase	*P*-value
Mean ± SD	Mean ± SD	Mean ± SD	
33.8 ± 1.1 ^{c}	36.6 ± 2.8 ^{b}	44.0 ± 2.8 ^{a}	<0.001*

**: Significant at $P \leq 0.05$, Different superscripts in the same row are statistically significantly different*

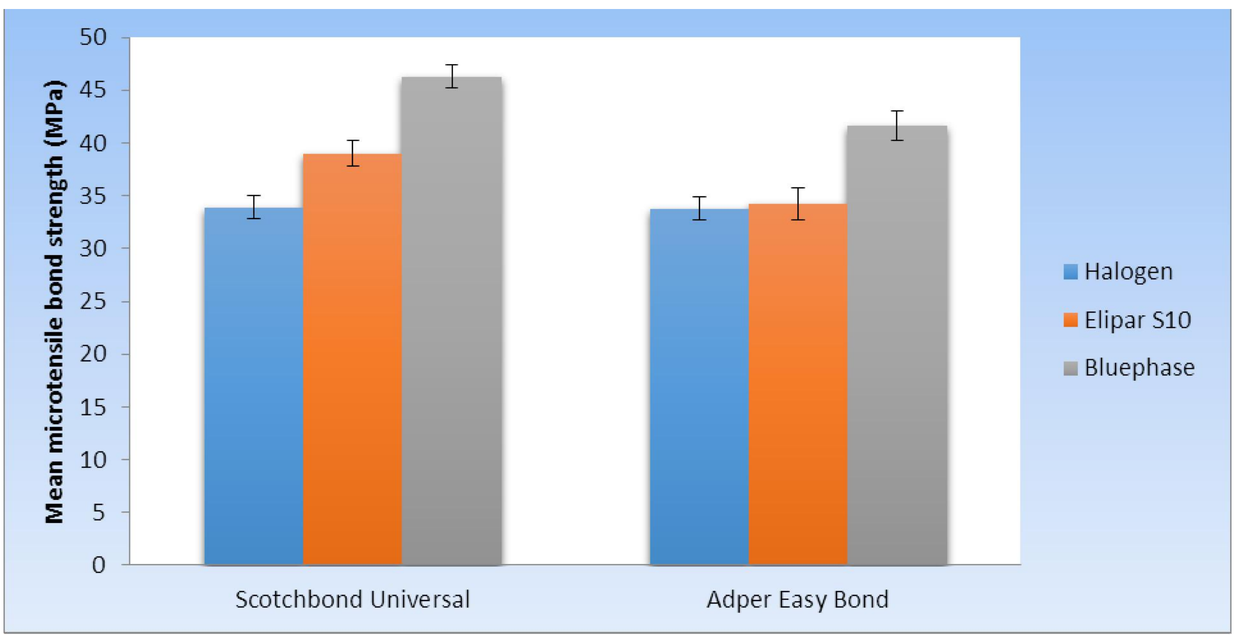

Figure (2): Bar chart representing mean and standard deviation values of microtensile bond strength in the different groups

3. Discussion:

To satisfy the requirements of a successful resin composite restoration, a strong bond should be achieved at the tooth-restoration interface. Consequently, the bond strength of the restorative materials can predict their clinical behavior and longevity. Therefore, in this study, microtensile bond test was used to evaluate the bond strength of two adhesive systems each have different approaches. Scotchbond Universal Adhesive (SU) using etch and rinse technique (also known as total-etch) and Adper Easy Bond Adhesive (EB) using self-etch technique after being cured using three different light curing units. Microtensile bond strength test is the best for evaluating the long-term durability of resin/dentin bonds, since the tensile force will be concentrated on the bonded interface during testing due to the small thickness of the sticks (0.8 mm^2 thick)[9]. Furthermore, each tooth produces multiple specimens thus delivering a perception about the strength of the restorative material adhesion [9]. However, reliability of bond strength data depends on the number of specimens as a minimum of 30 specimens should be available for testing[26] and this study tested 54 specimens in each group.

The result of this study made it necessary to accept the first null hypothesis, since, the bond strength values of the tested etch and rinse adhesive is higher than those of the tested self-etch adhesive regardless of the used curing unit. This may be attributed to the fact that, the quality of the hybrid layer and the number and length of resin tags[27, 28] are directly related to the strength and durability, and therefore a uniform and dense hybrid layer can obtain better bonding effect[29]. With etch and rinse system, the use of phosphoric etching removes the entire smear layer. Consequently, a relatively thick zone of demineralized dentin is produced[30] which is subsequently infiltrated completely with the adhesive monomers resulting in the formation of a thick uniform hybrid layer.

Meanwhile, the self-etching system produces a thinner hybrid layer, because the acidic resin monomer instantaneously demineralizes dentin and penetrates the smear layer covered dentin[30], since the smear layer is not removed. Moreover, self-etch adhesives contain both hydrophilic and hydrophobic components which provide antagonistic properties, thus, forming a hybrid layer with incomplete adhesive penetration into the dentin substrate[31]. Furthermore, the remaining uncured acidic monomers may continue etching the dentin, affecting negatively the bonding interface[32, 33].

The results of this study were in accordance with Aggarwal *et al.,* they reported that, the µTBS of total-etch adhesives on both normal and caries-affected dentin was higher than the self-etching adhesives[31]. Likewise, Sheets *et al.* and Bastos *et al.,* found that pre-etching of the dentin surface with phosphoric acid increases the bond strength significantly in comparison with self-etching systems[34,35]. Similarly, Van Landuyt *et al.,* stated that, self-etching adhesive systems, particularly the one-step type, tend to present lower bond strength than the conventional three-step systems, and they are not always easier to apply[5].

However, these findings were in contradiction with Anja *et al.,* as they found that, there was no significant difference in µTBS between the etch-and-rinse and self-etching adhesives to dentin regardless of endodontic irrigation regimens[2]. Moreover, Ayar, concluded that, bonding effectiveness of one-step self-etch adhesive systems to pulp chamber dentin was comparable to two-step self-etch and three-step etch-and-rinse adhesive systems[36]. Similarly, several studies reported that there was no significant difference between the bond strength values of self-etching and conventional adhesive systems[3,37].

According to the results of the present study, there was no statistically significant difference between the mean microtensile bond strength values of the two tested adhesive systems when only cured with the halogen curing unit. This could be the result of the chemical composition of the tested adhesives since both of them contain Vitrebond Copolymer and the type of the photoinitiator.

Currently, the dental professional has a wide variety of light curing units available on the market, such as conventional halogen, light emitting diodes (LEDs), plasma arc and Argon ion laser light units. The success of the bonding to the tooth substrates is strongly related to the light curing unit efficacy, which will induce adequate materials polymerization[38]. For this, the present study was also conducted to assess the effect of different light curing units on the durability of resin composite restorations, in terms of microtensile bond strength, with two different contemporary dentin adhesives.

In the present work, the second hypothesis was rejected, since, it was found that, Blue phase curing unit showed the statistically significantly highest mean microtensile bond strength. Followed by Elipar S10 curing unit showed statistically significantly lower mean microtensile bond strength. Whereas, halogen curing unit showed the statistically significantly lowest mean microtensile bond strength. This indicated that, both tested LED units promote better bond strength than the tested halogen unit. This could be attributed to that, the degree of conversion of the light-cured resin composites is directly proportional to the light intensity of the curing units[39]. Moreover, the output of the halogen curing light has a broad spectrum, thus a great portion lies outside the camphorquinone (CQ) absorption curve, so 80% of the energy from the halogen lamp is outside the required curing range[40, 41].

The results of this study were in accordance with Krämer *et al.* and Neumann *et al.,* who reported that, blue (LED) lamps offer the highest photo polymerization efficiency[42, 43]. Moreover, Mousavinasab and Meyers, found that the LED light gave better performance than the high power halogen light with respect to hardness and depth of cure[44].

However, the findings of this study are in contradiction with Nomura *et al.,* who reported that, the bond strength values of the resin composites cured with LED light curing units were significantly lower than those produced with QTH light curing unit[45]. They attributed that to the narrow emission spectrum of the LED light curing unit which cannot properly activate co-initiator with a different absorption spectrum from CQ[46, 47]. Furthermore, Lima *et al.,* concluded that, the QTH lamp promotes better values on the degree of conversion within the nanofilled composite resin than the LED lamp[48].

A noteworthy finding of this investigation was that, Bluephase curing unit showed the highest mean microtensile bond strength values. Meanwhile, Elipar S10 curing unit showed lower mean microtensile bond strength values. This could be explained by the fact that, Bluephase utilizes polywave technology which features a second spectral peak at approximately 410 nm in addition to the peak at approximately 470 nm. The polywave Bluephase Style covers a wavelength spectrum of between 385 and 515 nm. Thus, producing higher polymerization than Elipar S10 which utilizes single peak[14].

Conclusions:

Under the circumstances of this study:

Regardless of the used curing unit, the tested etch and rinse adhesive system provided better durability, in terms of microtensile bond strength. On the other hand, although Bluephaselight curing unit achieved the best microtensile bond strength values, both tested LED light curing units enhanced the bond strength much better than the tested halogen light curing unit.

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