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Evaluation of micro tensile bond strength of newly introduced universal adhesives using different bonding strategies and lining technique on human dentin: In-vitro study

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Aim: This study evaluated the immediate and aged micro-tensile bond strength (µTBS) of two universal adhesives: OptiBond eXTRa™ (Kerr) and BeautiBond Xtream™ (Shofu). It also investigated the impact of applying a flowable composite over the adhesive before placing the composite resin restoration, and analyzed fracture modes and the resin/dentin interface via SEM.
Materials and methods: Eighty human molars were randomly assigned to eight groups based on adhesive type, bonding strategy (Etch-and-Rinse [E&R] vs. Self-Etch [SE]), whether a flowable composite was used, and aging periods (24 hours and 6 months). The bonding procedures involved specific etching, adhesive application, and curing protocols, followed by micro-tensile testing at a rate of 1 mm/min.
Results: Indicated significant interactions between the adhesive type and bonding strategy, as well as between bonding strategy and aging time. After 24 hours, no significant difference in µTBS was observed between E&R and SE. However, the application of a flowable composite significantly enhanced bond strength in the Kerr adhesive compared to Shofu. Notably, bond strength diminished significantly after six months.
Conclusion: the two-step universal adhesive demonstrated superior bond strength and durability due to better hybrid layer formation, while the E&R strategy proved more effective than SE. Incorporating a flowable composite lining enhanced bonding effectiveness for both adhesive types, regardless of the bonding mode employed.

Keywords: micro tensile bond strength, universal adhesive, adhesion strategy, lining technique, failure mode, scan electron microscope.

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Introduction

Dental bonding systems have seen substantial advancements in recent years, primarily due to the growing demand for adhesive restorations. The latest trend in this field is the universal or multi-mode adhesive system. While the term "universal adhesive" (UAs) emerged in some studies in the early 1990s, it now denotes a versatile adhesive system that can be applied in etch-and-rinse (E&R), self-etch (SE), or selective-etch modes. [1,2] Although the initial bonding effectiveness of recently available dental adhesives is typically satisfactory, maintaining strong bond durability over the long term remains a challenge in dental practice, indicating that further improvements are needed.[3]

Dentin is a difficult tissue to bond with, creating nearly below 10 µm hydroxyapatite (Hap) hybrid layer (HL). SE adhesives utilize acidic groups in their functional monomers, allowing them to combine etching and priming in a single, mild process without the need for rinsing and drying. [4] Also UAs have lower resin content and higher solvent levels compared to when the primer was separated from the adhesive resin. Inadequate polymerization can result from oxygen interference, weakening the adhesive interface and reducing its stress absorption capacity.[5] UAs are more hydrophilic, limiting their effectiveness in creating a hydrophobic interface and increasing moisture absorption,[6] which undermines their hydrolytic stability. HEMA monomers further contribute to moisture retention at the adhesive interface.Which can lead to faster degradation of the bond over time. As a result, there has been a recent trend toward marketing HEMA free UAs.[7]

As previously stated, the thickness of thin films of UAs typically measures less than 10 µm, is a possible UA fragility which act as semi-permeable membrane. In-vitro investigations have consistently showed that incorporating an additional bonding layer or application of multi-layers of adhesives enhances bonding performance. [7, 8, 9, 10, 11]. But in the same time it may lead to comparatively increase film thickness of the adhesive layer with its adverse effects.[7, 12, 13] Polymerization of overlaying restorative composite shrinks, causing tensile tension at the adhesive interface. Introducing an elastic intermediary layer of appropriate thickness between the rigid dentin and the shrinking composite may assist absorb this stress and maybe prevent interfacial debonding. [5,14,15]. A more flexible flowable composite layer is expected to behave in a similar manner and could be advantageous, particularly when restoring cavities with high C-factor that are prone to high polymerization shrinkage stress.[5,7,12]

Introducing OptiBond eXTRa ™ (Kerr) Universal. Its two-component formulation dependability of a self-etch method, offering a consistent protocol. BeautiBond Xtream ™ (Shofu) is another innovation harnessing (the power of one HEMA free) UAs that bonds to all restorative substrates. As a result, despite the claims made in marketing, a newly introduced dental adhesive cannot be assured to function reliably in a variety of laboratory and clinical settings until thoroughly studied.[7]

The aims of this study were 1) to determine the immediate and aged micro-tensile bond strength (µTBS) effectiveness of the newest two introduced UAs, OptiBond eXTRa ™ (Kerr) Universal (two-component system and HEMA containing) and BeautiBond Xtream ™ (Shofu) universal adhesive (all in one system and HEMA free). Using E&R and SE adhesion strategies. And 2) to asses µTBS and determine the possible enhancement of bond strength of an extra flowable composite applied over the adhesive and beneath the overlaying composite resin restoration.3) evaluate the failure modes of fractures of both UAs. And 4) Scan Electron

Microscope (SEM) evaluation of resin/ dentin interface of both UAs. The null hypotheses investigated were that 1) no difference in µTBS between UAs under investigation using different adhesion strategies in both intervals.2) the additional flowable composite layer has no effect on bond strength on both UAs.

Materials and Methods

OptiBond eXTRA universal adhesive, BeautiBond Xtream universal adhesive, Beautifil flow plus F03 and Optishade universal nanohybride restorative composite used in this study and illustrated in table 1.

Table 1: Materials of the study.

Material type	Lot#	Chemical composition	Manufacturer
OptiBond eXTRa™ Universal Two components self-etch universal adhesive)	Primer:A153690 Adhesive:A153697	**-Self-etch-primer**: GPDM,HEMA,acetone , -ethylalcohol **Adhesive:**GPDM, HEMA,glycerol dimethacrylate,ethyl alcohol,sodium hexafluorosilicate,15% filled with 0.4 micron barium glass to help reinforce bond strength	Kavo Kerr corporation, orange, CA, USA
BeautiBond Xtreme	112251	Quad-AdhesiveTechnology, featuring Phosphate Ester, Dithiooctanoate,Carboxylic Acid monomers, acid resistant sialne. HEMA free formula, film thickness 5 µm	SHOFU.INC , Japan
Beautifil flow plus F03	062360	Bis-GMA, TEGDMA. S-PRG filler based on fluoro-boro-alumino-silicate-glass. Polymerization initiator.	SHOFU.INC , japan
Optishade universal nanohybride restorative composite Medium shade	A166262	BisGMA,BisDMA,TEGDMA, -Spherical silica and zirconia particles ,effective particle size is 5–400 nm) and 400 nm barium glass particles.-Filler loading 81% by wt. (64% by vol)	Kerr corporation, CA, USA
(Actino Gel)	PK2122820	37% Phosphoric acid, H_2O xanthan gel.	Prevest DenPro,Ltd, USA

Sample size calculation

A power analysis was conducted to ensure sufficient power for testing the null hypothesis, which proposed no difference in micro-tensile bond strength between groups. The analysis used an alpha level of 0.05, a beta level of 0.02 (corresponding to 80% power), and an effect size (f) of 0.508, derived from a prior study.[35] Based on these parameters, the required total sample size was determined to be 80, with the calculation performed using R software version 4.4.1 for Windows.[36]

Study design

This study used a total of 80 human molars. Teeth were gathered with TUCDREC-030924 clearance from the Ethics Committee Board at Taibah University's Faculty of Dentistry. After complete cleaning, eighty molars teeth were stored in distilled water at 4°C for up to three months after extraction, with the water being changed weekly. The teeth were then randomly assigned to eight different experimental groups for both time intervals, 40 molars for each tested UA (n = 5) based on two main groups according to universal adhesive investigated in this study; Group1: OptiBond eXTRa ™ (Kerr) and Group 2: BeautiBond Xtreme ™ (SHOFU). Each main group divided into two groups according to bonding strategies: A) E&R, B) SE, each bonding strategy group divided into subgroups according to lining technique :a) without using flowable composite b) with flowable composite layer. Each further subdivided for 24 hours testing and 6 months testing.

Teeth preparation

The teeth were embedded in acrylic resin blocks to a level 1mm below the CEJ and then mounted on an automated diamond saw (Isomet 4000, Buehler Ltd., Lake Bluff, IL, USA) was used for all sectioning in this study. The occlusal surfaces were flattened slightly below the DEJ with a low-speed abrasive with a water coolant.

Dentin surfaces were wet ground with silicon carbide (SiC) sheets #180 to remove any residual enamel. Prior to bonding procedures wet grind each dentin surface with SiC sheet #600 for 30 seconds to establish a consistent smear layer.

Bonding procedures

In the ER protocol, dentin surfaces were treated with 37% phosphoric acid for 15 seconds before being rinsed with water for 30 seconds and blotted dry to remain moist. In the SE mode, no acid etching was performed. For the OptiBond eXTRa universal bond system, the primer was shaken for 5 seconds and applied to both etched and un-etched dentin surfaces for 20 seconds, followed by 5 seconds of air drying. The adhesive was also shaken for 5 seconds, applied for 15 seconds, and air dried for another 5 seconds. Finally, the adhesive was light cured for 10 seconds using a 1400 mW/cm² LED light curing system (Elipar™ DeepCure-L, 3M ESPE, USA).

For the BeautBond Xtreme universal bond, the adhesive was actively applied to both etched and un-etched dentin surfaces for 20 seconds and then air-dried for 5 seconds per manufacturer recommendations another coat could be added till uniform glossy appearance of the adhesives layer was obtained after air drying. The adhesive was light polymerized for 5 sec.

In groups without a flowable composite lining, a restorative composite was applied directly over the cured adhesive in increments of 4 mm. For groups with a flowable composite lining, a uniform layer of 0.5 to 1 mm was first applied over the cured adhesive, then light cured for 10 seconds according to manufacturer recommendation followed by the restorative composite, also added incrementally to a height of 4 mm and light cured. The immediate specimens were stored in distilled water at 37°C for 24 hours before being sectioned , For the aged groups the whole teeth were aged for an additional 6 months before sectioning.

µTBS testing

The restored teeth were sectioned using an automated diamond saw to create 1x1 mm² beams, cutting perpendicular to the composite-adhesive-dentin interface in both x and y directions. Beams with dentin thickness greater than 2 mm were selected, resulting in beams measuring 1 ± 0.1 mm thick. A digital caliper was used to measure the thickness and length of all beams. For each experimental group, 80 beams were randomly chosen for µTBS testing, divided into two aging groups: 24 hours and 6 months (n = 40), stored in distilled water at 37°C. Any beams that failed during sectioning, fixing, or storage were excluded from analysis. Each beam was individually attached to a metallic jig using cyanoacrylate adhesive, ensuring at least 1 mm distance from the adhesive interface. The jig was then mounted in a universal testing machine (Instron, MA, USA), where a tensile load was applied at a speed of 1 mm/min until failure occurred. Bond strength was measured in megapascals using (Bluehill Lite software, Instron, MA, USA)

Examination of failure mode

Each fractured beam was examined using a stereomicroscope at 40X magnification (Nikon MA 100, Tokyo, Japan) to assess the failure modes. The fractures were classified into four categories:
1-Adhesive Failure: Occurs at the interface of composite, adhesive, and dentin.
2-Mixed Failure: Involves failure at the composite/adhesive or dentin/adhesive interface, part of the adhesive, dentin, or composite was damaged.

3-Cohesive Composite: Failure happens within the composite restoration itself.
4-Cohesive Dentin: Failure occurs within the dentin.

SEM evaluation

A total of 16 human molars were used to evaluate the resin/dentin interface, categorized into eight experimental groups for two different time intervals. The preparation involved flattening the dentin surface, applying a smear layer, and constructing a composite crown, as outlined for µTBS testing. After being stored in distilled water for 24 hours or six months, the crowns were sectioned vertically to create two central slabs, each about 2 mm thick. These slabs underwent a series of surface preparations: they were wet-ground with silicon carbide (SiC) paper in ascending grits (600, 800, and 1200) for one minute each, followed by ultrasonic cleaning in distilled water for two minutes. The surfaces were then acid-etched with 37% phosphoric acid gel for 10 seconds, rinsed for 20 seconds, and air-dried. Following this, specimens were immersed in 5.25% sodium hypochlorite for two minutes and thoroughly washed under running water for five minutes. They were dehydrated in increasing concentrations of alcohol (50%, 70%, 95% for 20 minutes each, and 100% for one hour) before being stored overnight in closed containers on absorbent paper. Before evaluation, each specimen was mounted on a metallic stub with double-faced adhesive tape and gold sputter-coated. The resin/dentin interfaces were examined using a SEM (Hitachi S3500, Japan) at 30 kV, capturing images at magnifications of 500x, 1000x, and 2000x.

Statistical analysis

Numerical data were reported as means with 95% confidence intervals, standard deviations (SD), and minimum and maximum values. Normality and homogeneity of variance were assessed using visual distribution checks and Shapiro-Wilk's and Levene's tests. A three-way ANOVA was conducted for analysis, with simple effects comparisons utilizing the multifactorial model's error term and adjusting p-values via the False Discovery Rate (FDR) method. The significance threshold was set at $p < 0.05$ for all tests. Statistical analyses were conducted using R software version 4.4.1 for Windows.[36]

Results

Descriptive statistics for µTBS are carried on. The three-way ANOVA results in Table 2 indicate a significant interaction between material and treatment ($p < 0.001$) as well as between treatment and time ($p = 0.029$).

Table 2: Three-way ANOVA

Source	Sum of squares (III)	df	Mean square	*f-value*	*p-value*
Material	0.13	1	0.13	2.54	0.113
Treatment	1.61	3	0.54	10.74	<0.001*
Time	2.68	1	2.68	53.66	<0.001*
Material * treatment	1.64	3	0.55	10.92	<0.001*
Material * time	0.05	1	0.05	0.93	0.337
Treatment * time	0.46	3	0.15	3.09	0.029*
Material * treatment* time	0.19	3	0.06	1.26	0.291

df degree of freedom, * significant (p<0.05).

The comparisons of simple effects in Table 3 indicated that, after 24 hours, samples treated with E&R and SE showed no significant difference in bond strength (p=0.113 and p=0.425). However, when a flowable composite layer was applied in both bonding strategies, the Kerr samples exhibited significantly higher bond strength values compared to the Shofu samples (p<0.001 and p=0.016).

For samples measured after 24 hours, Kerr samples treated with E&R+flowable had significantly higher values than those treated with other protocols (p<0.001). In contrast, Shofu samples treated with E&R had significantly higher bond strength than those treated with SE. (p=0.015).

For samples measured after six months and treated with SE, the difference was not statistically significant (p=0.919). For samples treated using E&R, Shofu samples had significantly higher bond strength (p=0.004). For samples treated with E&R+flowable and SE+flowable layer, Kerr samples had significantly higher values (p<0.001 and 0.038).

For samples measured after six months, Kerr samples treated with E&R+flowable had significantly higher bond strength than those treated with other protocols (p<0.001). Additionally, samples treated with SE and SE+flowable had significantly higher values than those treated with E&R (p<0.001). For Shofu samples, the difference in bond strength between different treatments was not statistically significant (p=0.128).

The comparisons of simple effects presented in Table 4 showed that regardless of restorative material and treatments, there was a significant reduction in measured bond strength after six months.

Table 3: Simple effects comparisons (A)

Time	Treatment	µTBS (MPa) (Mean±SD)		*f-value*	*p-value*
		OptiBond eXTRa	**BeautiBond Xtreme**		
24 hours	**E&R**	3.35 ± 0.20^{B}	3.51 ± 0.21^{A}	**2.54**	**0.113**
	SE	3.33 ± 0.22^{B}	3.25 ± 0.26^{B}	**0.64**	**0.425**
	E&R+fl.	3.83 ± 0.24^{A}	3.20 ± 0.25^{B}	**39.29**	**<0.001***
	SE+fl lay	3.54 ± 0.23^{B}	3.29 ± 0.21^{AB}	**5.92**	**0.016***
	f-value	**10.74**	**3.60**		
	p-value	**<0.001***	**0.015***		
6 months	**E&R**	2.62 ± 0.22^{C}	2.91 ± 0.28^{A}	**8.73**	**0.004***
	SE	2.84 ± 0.19^{B}	2.83 ± 0.25^{A}	**0.01**	**0.919**
	E&R+fl.	3.53 ± 0.21^{A}	2.68 ± 0.21^{A}	**72.69**	**<0.001***
	SE+fl lay	3.03 ± 0.19^{B}	2.82 ± 0.18^{A}	**4.39**	**0.038***
	f-value	**30.24**	**1.92**		
	p-value	**<0.001***	**0.128**		

Values with different superscripts within the same vertical column are significantly different, * significant (p<0.05).

Failure modes analysis

The analysis of fracture modes across various specimens revealed that the 'mixed failure' mode was predominantly observed in BeautiBond extreme Shofu, whether applied using SE or E&R modes without a flowable composite layer, both immediately and after aging. In contrast, the two-step UA OptiBond eXRTa Kerr showed a more balanced distribution of failure modes. Aging did not significantly alter the distribution of these modes when a flowable composite layer was applied, meanwhile there was a notable increase in 'adhesive failure' for both UAs when used in SE bonding mode without the flowable layer.

Table 4: Simple effects comparisons (B)

Material	Treatment	Micro-tensile bond strength (MPa) (Mean±SD)		*f-value*	*p-value*
		24 hours	6 months		
OptiBond eXTRa	E&R	3.35±0.20	2.62±0.22	53.66	<0.001*
	SE	3.33±0.22	2.84±0.19	24.51	<0.001*
	E&R+fl.	3.83±0.24	3.53±0.21	9.15	0.003*
	SE+fl lay	3.54±0.23	3.03±0.19	25.63	<0.001*
BeautiBond Xtreme	E&R	3.51±0.21	2.91±0.28	35.56	<0.001*
	SE	3.25±0.26	2.83±0.25	18.08	<0.001*
	E&R+fl.	3.20±0.25	2.68±0.21	27.91	<0.001*
	SE+fl lay	3.29±0.21	2.82±0.18	22.32	<0.001*

*** Significant.**

SEM evaluation

Representative SEM images of resin/dentin interface of all study groups are displayed in Fig.1 for immediate hybrid layer HL investigations and Fig 2. For aged HL investigations. Arrows indicated thick HL.

Discussion

Simplifying adhesive protocols aims to enhance usability, but this may compromise bonding efficiency and durability. To maintain bond strength, it's essential to seal the adhesive dentin interface by a hydrophobic layer, especially in dentin, which is prone to aging. UAs typically come as a one-step solution, combining primer and adhesive resin in a single step. While this approach creates a balanced chemical composition, it often results in a somewhat hydrophilic interface that can absorb water,[16, 17] leading to bond degradation over time due to hydrolysis. UAs generally have a low thickness (under 10 µm), influenced by their solvent content and application technique. A thin layer may not cure well in oxygen rich layer, resulting in an unstable interface under stress from restorative composites. To address these issues, new two-step UAs have been developed to separate the priming and sealing functions. This separation allows for a more hydrophobic seal and a thicker adhesive resin film, which provides better protection and stability for the hybrid layer.

Based on the study's findings, both null hypotheses should be rejected. The factors examined namely "type of UAs," "adhesive strategy," "additional layer of flowable composite," and "aging" all had a significant impact on µTBS.

In terms of adhesive mode, after a 24-hours testing, there was no significant difference observed between the two adhesive strategies SE and ER without flowable composite layer (p=0.113 and 0.425) except for BeautiBond eXtreme samples treated with E&R had significantly higher bond strength than those treated with SE. (p=0.015).[17, 18, 19]

However, for samples treated with E&R+flowable and SE+flowable layer, OptiBond eXTRa samples had significantly higher values than BeatiBond eXtreme (p<0.001 and 0.016).

An increase in bond strength was observed when a 0.5-1 mm thick layer of flowable composite liner was placed between two UAs and restorative composite, regardless of the bonding mode used. Flowable composites contain less filler and are less stiff (20-30% lower stiffness) than restorative composites, allowing them to act as stress-absorbing layers and help to stabilize the resin/dentin interface. As well as flowability and wetting ability of the flowable composites and their role in intimate covering of the adhesive layer. [3, 7, 12, 21]

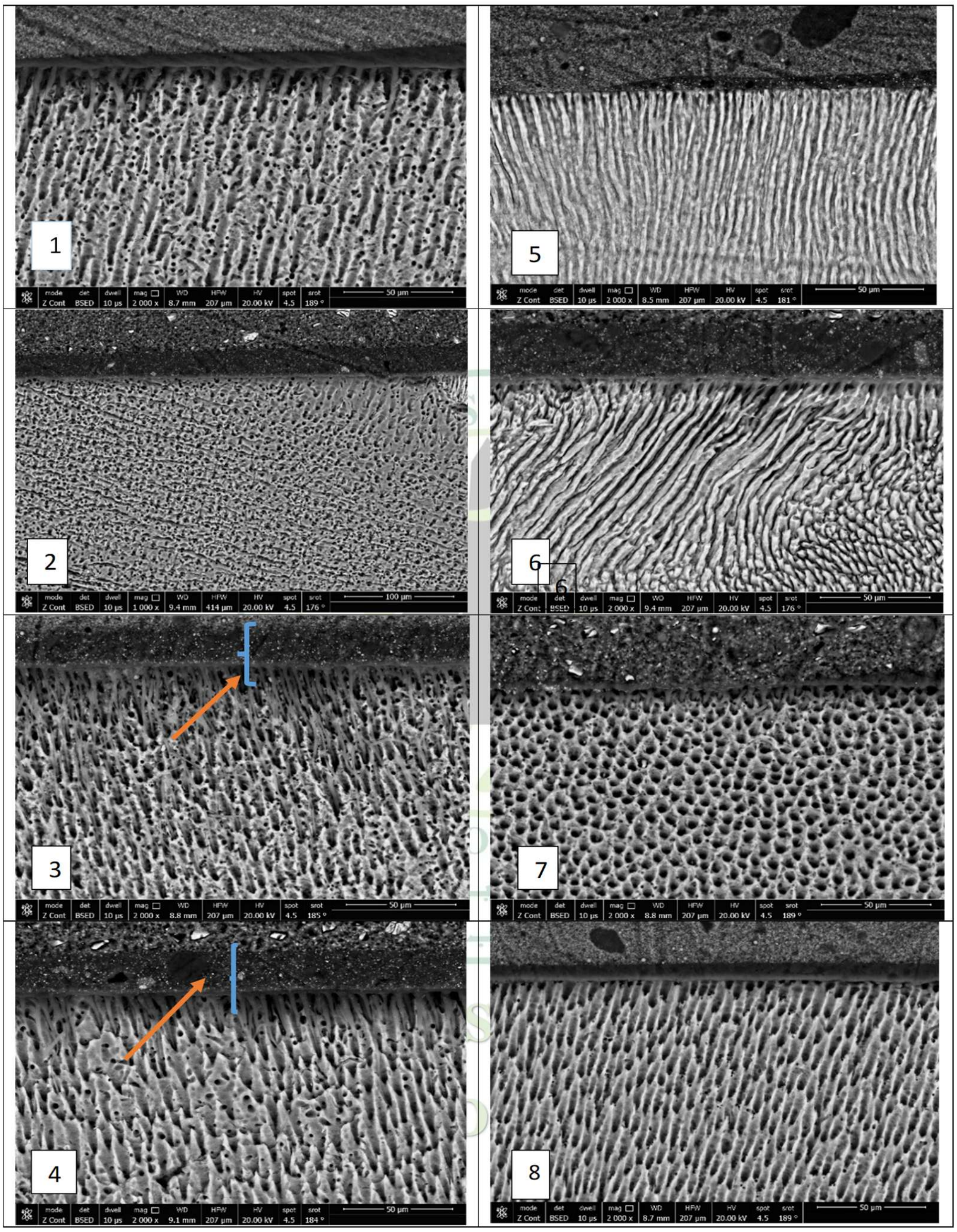

Figure 1: Immediate SEM photos of resin/dentin interface of investigated groups, OptiBond eXTRa (left column) and BeautiBond extreme (right column): 1) kerr UA with E&R protocol without flowable composite layer. 2) Kerr UA with SE protocol without flowable. 3)Kerr UA with E&R protocol with flowable layer. 4)Kerr UA with SE protocol with flowable layer. 5)Shofu UA with E&R protocol without flowable composite layer. 2) Shofu UA with SE protocol without flowable. 3)Shofu UA with E&R protocol with flowable layer. 4)Shofu UA withSE protocol with flowable layer. Arrows indicates thick hybrid layers.

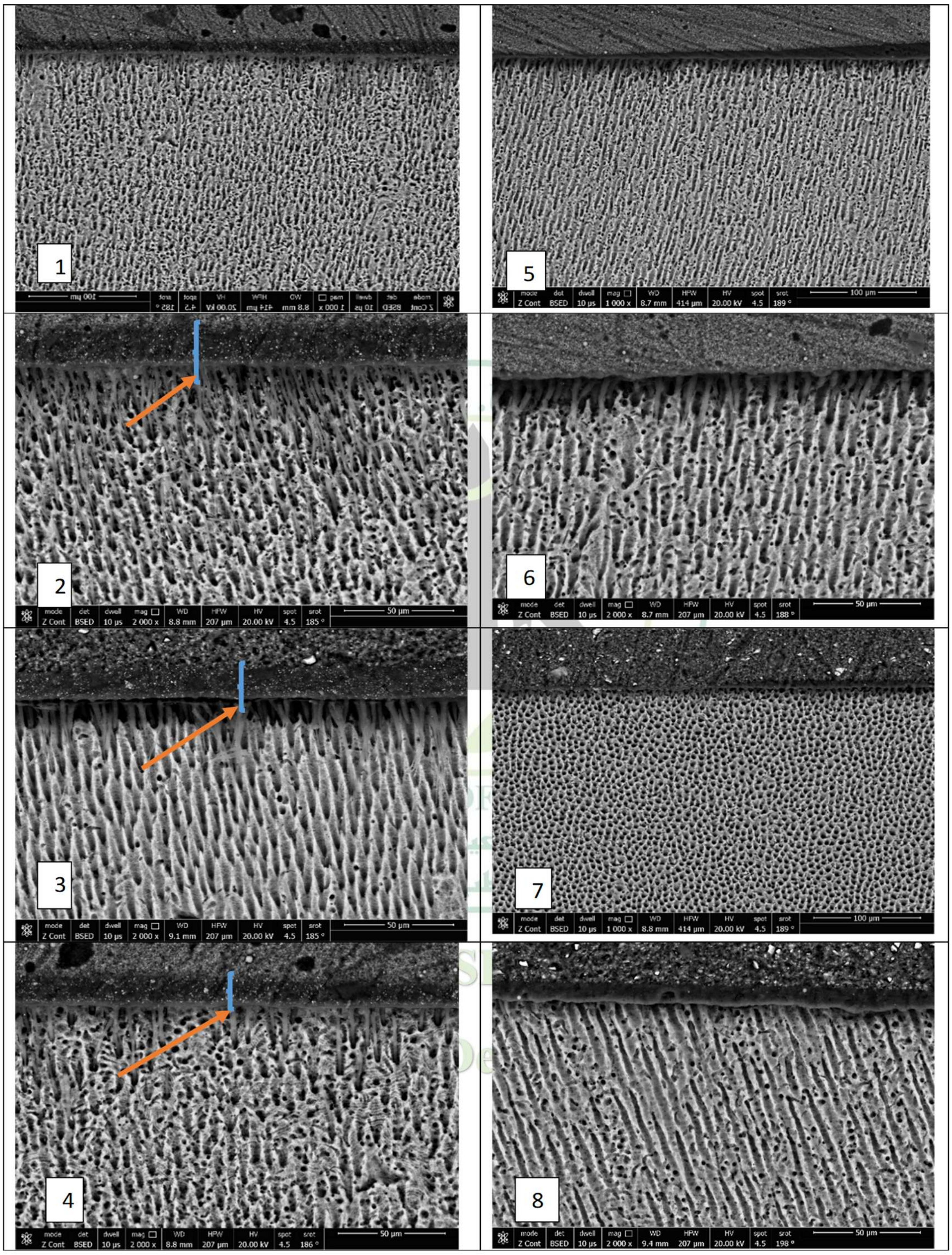

Figure 2: Aged SEM photos of resin/dentin interface of investigated groups after 6 months, OptiBond EXTRa (left column) and BeautiBond extreme (right column):): 1) kerr UA with E&R protocol without flowable composite layer. 2) Kerr UA with SE protocol without flowable. 3)Kerr UA with E&R protocol with flowable layer. 4)Kerr UA withSE protocol with flowable layer. 5)Shofu UA with E&R protocol without flowable composite layer. 2) Shofu UA with SE protocol without flowable. 3)Shofu UA with E&R protocol with flowable layer. 4)Shofu UA withSE protocol with flowable layer. Arrows indicates thick hybrid layers.

The µTBS showed a statistically significant improvement with the two-step OptiBond eXTRa UA when the flowable composite layer was included. Thus could be explained by the considerably thicker 2-step UA OptiBond eXTRa was better at absorbing stress due to its increased thickness. This more thick resin adhesive layer likely offered enhanced protection for the bond to dentin, helping to prevent it from being separated by the tensile stress generated by the overlaying shrinking restorative composite.[3] The data show that separating the step of hydrophilic primer from the step of hydrophobic adhesive functioned in a two-step UA application improved bond strength in both adhesion strategies. The primer served as an adhesion promoter, allowing the hydrophobic adhesive to effectively wet and penetrate the pre-primed dentin substrate. The solvent-free adhesive resin was applied in a thick layer to ensure sufficient polymerization. In contrast, the one-step UA struggled to handle the high stress, resulting in significantly lower µTBS and less durable bonding, particularly noted with BeatiBond eXtreme. [3, 20, 22, 23]

The study found that adhesives showed better immediate and aged bonding effectiveness when applied using the E&R mode instead of the SE mode. Since after 24 hours BeautiBond eXtreme samples treated with E&R showed significantly greater bond strength than those treated with SE ($p = 0.015$).While after 6 months BeautiBond eXtreme samples treated with E&R exhibited significantly higher bond strength ($p=0.004$). This was in agreement with Moritake et al. [26] as they observed after 6 months aging, the ER mode showed a significant increase in bond strength compared to the SE mode. They observed that both the type of adhesive and storage conditions influence shear bond strength. They reported that the SE mode of various UAs often resulted in either a very thin or absent hybrid layer. Their research indicates that the effect of storage conditions on bond strength varies depending on the adhesive type, regardless of how it is applied.[26]

Pre-etching the dentin before applying UA improved the adhesives' penetration into demineralized dentin, resulting in a thicker HL and well uniformed resin tags compared to the SE mode.[24]The researchers observed that the thickness of the hybrid layer was associated with bond strength, attributing the higher bond strength in the E&R mode to its ability to create a thicker hybrid layer. [24, 25]

In both application modes of adhesives, a 6-month aging led to a notable reduction in µTBS values of the UAs to dentin. Toledano et al.[27] investigated how different storage conditions, either direct or indirect exposure of the aged specimens to various media, influenced the durability of µTBS for various adhesives. They found that the storage method significantly impacted bond strength, particularly when water was used as the medium. Direct exposure to water caused water absorption at the bonded interface, leading to plasticization of the resin and a gradual weakening of the bond strength over time.[27]

Another possible explanation for the reduced bonding performance of the one-step Shofu UA in this study could be the requirement to air-dry the adhesives thoroughly before curing. This step is crucial for removing excess solvent and water droplets that can form during dispensing, as indicated by the manufacturer's HEMA-free formulation.[28, 29, 30,31, 32]

In general, it's important to allow the solvent either in the primer of two-steps adhesives, or in that incorporated with adhesive resin of one-step adhesives, to evaporate as much as possible through air-drying. If this doesn't happen, residual solvent can inhibit polymerization, and in HEMA-free adhesive formulations, phase separation may lead to porosities that trap residual solvent within the adhesive interface.[33, 34]

Limitation and recommendation

This study evaluated a flat dentin surface, which may not accurately represent the complex morphology of dentin along the cavity walls. Variations in dentin structure can influence the adhesion and flow characteristics of the composite. Also absence of incorporation of thermo-cycling or chewing simulator during aging may limit the understanding of how the adhesives and composite materials perform under thermal stress, which is common in oral environments that could affect the longevity and durability of the restoration.

Future research should consider a wider range of cavity classes and designs to evaluate the performance of flowable composites over UAs. This could include assessing their behavior in Class I, II, V and other cavity types, which are common in clinical practice and present unique challenges and performance characteristics that were not explored in this study.

Conclusion

This study highlights the importance of:

1-The use of an elastic intermediate layer with a flowable composite can compensate the thin film thickness of both one-step and two-step universal adhesives, while also improving bonding effectiveness.

2- The two-step universal adhesive demonstrates superior bond strength and durability compared to the one-step universal adhesive. The enhanced performance of the two-step system can be attributed to its ability to create a more effective hybrid layer and improve the overall adhesion to dentin.

3- The E&R adhesion strategy demonstrated superior effectiveness compared to the SE strategy regardless of the adhesive system used.

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Data availability

The datasets from this study can be obtained from the corresponding author upon reasonable request.

Ethics approval

TUCDREC-030924 clearance from the Ethics Committee Board at Taibah University's Faculty of Dentistry. Saudi Arabia Al Madinah Al Monawarah.

Competing interest

The author stated that no competing interests.

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