ORIGINAL RESEARCH

A Comparative Evaluation of Shear Bond Strength of Embrace Wetbond^{TM} Pit and Fissure Sealant with or without the Use of a Universal Dental Adhesive System [Scotchbond^{TM} Universal Adhesive] Using Different Bonding Protocols: A Multiparametric *In Vitro* Study

Swathy RS[1], Jaya Naidu[2]

Abstract

Aim: To evaluate and compare the shear bond strength (SBS) of Embrace WetBond^{TM} (EWS) Pit and Fissure Sealant (PF sealants) with or without the use of a universal dental adhesive system Scotchbond^{TM} Universal Adhesive (SBU) using different bonding and curing protocols and to assess and compare the mode of failure as determined by visualization of the fractured surfaces of the test specimens after shear testing under an optical microscope at a magnification of 20×.

Materials and methods: A total of 85 samples were prepared for testing SBS on enamel on caries-free, extracted permanent human molars. The specimens were randomly divided into five groups based on different bonding and curing protocols. A knife-edge blade in a universal testing machine was used to perform the SBS test with a crosshead speed of 1 mm/minute. Then the mode of failure was assessed.

Statistical analysis: Results were analyzed using a one-way analysis of variance with Tukey's *post hoc* test and Chi-squared test. A probability value 0.05 ($p \leq 0.01$) was regarded as significant.

Results: Scotchbond^{TM} Universal Adhesive (SBU) in total-etch (TE) mode/etch-and-rinse (ER) mode with individual light curing of the sealant and adhesive showed the highest SBS to enamel (5.40 ± 2.51 MPa). A predominance of cohesive mode of failure was observed for all the test groups.

Conclusion: Embrace WetBond^{TM} (EWS) PF sealants with SBU in the ER mode of application, with either curing mode, can be used as an alternative to a conventional technique for sealant placement for improving interfacial bond strength to enhance sealant retention and efficacy.

Clinical significance: Embrace WetBond^{TM} (EWS) PF sealants with SBU in the ER mode of application can be used as an alternative to a conventional technique for sealant placement for improving interfacial bond strength.

Keywords: Embrace WetBond^{TM} pit and fissure sealant, Mode of failure, Scotchbond^{TM} Universal adhesive, Shear bond strength, Universal adhesive.

International Journal of Clinical Pediatric Dentistry (2023): 10.5005/jp-journals-10005-2500

Introduction

Pit and fissure sealants (PF sealants) are considered a foremost prevention technology in dental caries management, preferably used along with patient education, effectual individual oral hygiene, fluorides, and regular dental visits.[1] Most sealant materials in use today are resin-based materials. The moist oral environment poses clinical difficulties in their placement.[2] As salivary contaminations during sealant placement are the most common reason for failure, a moisture-tolerant resin-based sealant (RB sealant) is necessary.[3]

Embrace Wetbond^{TM} (EWS) PF sealants, a unique moisture-tolerant RB sealant with resin-acid integrated network (RAIN), making it hydrophilic.[2] EWS is bisphenol A-glycidyl methacrylate (Bis-GMA) and bisphenol A free, recommended on surfaces that are slightly moist and can be activated in the presence of moisture,[4] allowing placement during an early eruption.[2]

Although the performance of EWS clinically has been reported to be on par with contemporary sealants, a few clinical studies have reported an early loss of EWS.[4,5] Additionally, a significant increase in the SBS of EWS was reported in an *in vitro* study when the sealant was used along with an adhesive system.[6]

[1]Department of Pediatric and Preventive Dentistry, Thiruvananthapuram, Kerala, India

[2]Department of Pediatric and Preventive Dentistry, Vydehi Institute of Dental Sciences and Research Centre, Bengaluru, Karnataka, India

Corresponding Author: Swathy RS, Department of Pediatric and Preventive Dentistry, Thiruvananthapuram, Kerala, India, Phone: +91 9400122740, e-mail: swathyraj91@gmail.com

How to cite this article: Swathy SR, Naidu J. A Comparative Evaluation of Shear Bond Strength of Embrace Wetbond^{TM} Pit and Fissure Sealant with or without the Use of a Universal Dental Adhesive System [Scotchbond^{TM} Universal Adhesive] Using Different Bonding Protocols: A Multiparametric *In Vitro* Study. Int J Clin Pediatr Dent 2023;16(1):48–53.

Source of support: Nil

Conflict of interest: None

In general, to build a strong bond between adhesive and substrate, an adhesive must initially wet the substrate. Therefore, a successful bond is achieved only by enhancing the wettability of the tooth surface. Thus, the use of an enamel–dentine bonding agent as an intermediate layer could be beneficial, although it extends the time needed for the sealant placement.[7]

Self-etching (SE), ER, and "selective enamel etching" techniques can be used for universal adhesives (UA), as recommended by manufacturers. SBU is a unique dental adhesive that is multimode in nature and has high moisture tolerance that reportedly displays compatible bonding on both moist etched and dry etched dentin and enamel and also exhibits hydrophilic properties at the time of placement and hydrophobic properties upon polymerization.[8]

As there is a paucity of research regarding the SBS of EWS sealant along with SBU, the present research was aimed at comparatively evaluating the same using different bonding protocols.

Materials and Methods

The following materials were used:

- Embrace WetBond™ (EWS) PF sealants (EWS, Pulpdent™ Corporation).
- Scotchbond™ Universal Adhesive (SBU) (SBU, 3M ESPE, Saint Paul, Minnesota, United States of America).
- Etch-Rite™ (Pulpdent™ Corporation) (Table 1).

A total of 22 noncarious therapeutically extracted permanent molar teeth were chosen for the research after being approved by Institutional Ethics Committee. Inspection of the teeth was done to fulfill the following inclusion–exclusion criteria.

Inclusion Criteria

- Caries-free teeth.
- Intact unrestored teeth.

Exclusion Criteria

- Teeth with enamel hypoplasia.
- Dental restorations.
- Dental caries.
- Enamel crack.

Methodology

International Organization for Standardization (ISO)/TS 11 405:2015 (E) was used for processing and storing the selected teeth.[11] A diamond disk with water coolant was used to section the crowns of selected specimens from the roots at the cemento-enamel junction (CEJ), perpendicular to the long axis of the tooth. The roots were separated 2 mm below the CEJ. The crowns were then divided longitudinally in a mesiodistal direction and again sectioned buccolingually so that four equal sections were obtained. This process resulted in 88 tooth specimens, out of which three tooth specimens were excluded as only 85 specimens were required for the study.

Random allocation of the specimens to each group (n = 17/group) was done and kept in distilled water prior to testing specimens. Each group has given a single section of each tooth. Then these sections were fixed in acrylic resin using a custom-made cylindrical metallic mold (2.0 ± 0.1 cm diameter and 1.00 ± 0.1 cm height). Each crown section was embedded horizontally in acrylic resin with the sectioned buccal or lingual surface facing up using the custom-made standardized cylindrical metallic mold.

The specimens were removed from the mold once the acrylic resin was set. Both the enamel surfaces (buccal and lingual) of all the specimens were gritted wet with #400 silicon carbide (SiC) and then hand polished with #600 grit wet SiC paper for 30 seconds to provide a flat enamel surface to which the sealant buttons were bonded. Prior to the sealant button placement, cleaning of the test surfaces was done using fluoride-free pumice and a rubber cup and washed in running water to eliminate any residue.

After etching/and or bonding of the demarcated enamel bond sites as per the individual bonding protocols, a specifically designed custom-made split Teflon mold of 3 mm inner diameter and 2 mm height was positioned over the demarcated enamel sites and was stabilized in its place by means of another split metallic ring fitted inside the external cylindrical metallic mold. The Teflon mold was filled completely with the PF sealants, using a syringe with a disposable needle to avoid the inclusion of air bubbles. The material was light-cured as per curing protocols for EWS.

In accordance with the bonding protocol, random allocation of the 85 test specimens to five groups of equal size was done (Table 2).

Individual test tubes with deionized distilled water were used to store each specimen and were then placed in an incubator at 37°C immediately after bonding until testing. Blinding of the investigator, with regards to the test groups, was done at this point to avoid bias during testing.

The minimum storage period was set at 24 hours before conducting SBS testing, and the storage period did not exceed 7 days. A knife-edge blade in a Mecmesin universal testing machine at a crosshead speed of 1 mm/minute, until failure, was used for performing the SBS test. Then the SBS values in megapascal were

Table 1: Material description, composition, and manufacturer details of the materials used in the study

Material	*Chemical composition*	*Manufacturer*
EWS PF sealants[9]	36% by weight—glass filler contains di, tri multifunctional acrylate monomer in RAIN (silica, amorphous, uncured acrylic resin, and sodium fluoride)	Pulpdent™ Corporation LOT—190115
SBU (commercially available as Single Bond Universal in Asia-Pacific region)[8]	MDP phosphate monomer dimethacrylate resins, HEMA, Vitrebond™Copolymer, filler, ethanol, water, initiators, and silane	3M ESPE, Saint Paul, Minnesota, United States of America LOT—81219C
Etch-Rite™[10]	38% phosphoric acid Silica gel	Pulpdent™ Corporation LOT—190110

Table 2: Bonding and curing protocols for test groups

Groups	*Bonding protocol*	*Curing protocol*
Group I	EWS + acid-etching	Individual curing
Group II	EWS + SBU SE mode	Simultaneous curing
Group III	EWS + SBU SE mode	Individual curing
Group IV	EWS + SBU ER mode	Simultaneous curing
Group V	EWS + SBU ER mode	Individual curing

computed using the following formula—load of failure (Newton)/area of the cylindrical cross-section (CS).

After testing for SBS, the fractured surface of each tooth specimen was examined with an optical microscope (stereomicroscope, Carl Zeiss, Germany) to determine the mode of failure at a magnification of 20×. The mode of failure can be categorized as[12]:

- Adhesive failure: Complete debonding of the material.
- Cohesive failure: Within the material.
- Mixed failure: Partial adhesive failure and cohesive failure within the material.
- Enamel failure: Failure only in enamel.

Results

The highest mean SBS to enamel was exhibited by group V, followed by groups IV, I, II, and III, which demonstrated the lowest SBS value to enamel ($p \leq 0.01$) (Table 3). The mean SBS in group V (EWS + SBU; ER mode; individual curing) was significantly higher than both group II (EWS + SBU; SE mode; simultaneous curing) and group III (EWS + SBU; SE mode; individual curing), while no significant difference was noticed in the mean SBS values in comparison with group I (control) and group IV (EWS + SBU; ER mode; simultaneous curing).

The mode of failure analysis tested for groups V, I, II, and III demonstrated a predominantly cohesive type of failure followed by a mixed failure, while group IV demonstrated only a cohesive type of failure (Table 4). Chi-squared tests displayed no significant difference in the mode of failure for all the groups.

Discussion

Resin-based sealants (RB sealant) are mostly Bis-GMA-based sealants and other monomers that are primarily hydrophobic in nature, so they require a dry field.[2] EWS, an RB sealant, developed from a unique dental resin incorporating di, tri, and multifunctional acrylate monomers into a hydrophilic RAIN. It is claimed to be self-priming, hydrophilic, hydro-balanced, water-miscible, and can bond to slightly moist teeth, creating a leak-free interface.[13] It can bond to the tooth both chemically and micromechanically. It has a neutral pH after light curing and exhibits physicochemical properties similar to those of conventional sealants, making it almost insoluble in water.[4,13] In the presence of moisture, it flows on the surface and bonds to the tooth structure. Thus, it conventionally does not require a bonding agent.[2,13] Due to its optimal properties, EWS has been recommended for use in uncooperative children and in cases of difficult isolation.[5] Although the clinical performance of EWS has been reported to be on par with contemporary sealants by some researchers,[4,5] a few clinical studies have reported an early loss of retention of EWS when used alone.[14]

Interestingly, in an *in vitro* study, a significant increase in SBS of EWS was reported when the PF sealant was incorporated with the adhesive system.[6] Etching with 38% phosphoric acid before sealant application is recommended by EWS manufacturers. When the sealant is applied to etched enamel, the sealant penetrates into the microporosities and forms resin tags to a depth of 25–50 µm and, at times to a depth of 100 µm and is retained due to micromechanical bond.[15]

The routine technique of sealant application is applying it directly to the etched enamel. However, the efficacy of using a bonding agent before sealant placement has been assessed in different studies.[2,16] Bonding agents help overcome the dry field requirement and have the potential to increase sealant retention when used with traditional sealants.[2,16]

Scotchbond™ Universal Adhesive (SBU) is a distinctive dental adhesive with a unique set of properties, such as combined TE and SE bonding capability, consistent bond strength, and effectually no postoperative sensitivity in both TE and SE modes. It has high moisture tolerance, which allows consistent bonding to both dry etched and moist etched dentin. It can bond to indirect substrates without a separate primer due to its combined primer/adhesive capability and also has dual-cure capability with a separate dual-cure activation solution. SBU is compatible with conventional phosphoric acid etchants when employing with selective etch or TE bonding mechanism.[9]

The presence of methacryloyloxydecyl dihydrogen phosphate (MDP) monomer in its composition endows it with the SE property,

Table 3: Mean values of SBS to enamel in (MPa intergroup comparison using Tukey's *post hoc* test. The mean difference is significant at the 0.05 level. Same alphabets indicate no significant difference in value)

Groups	*N*	*Mean ± standard deviation*	*Standard error*	*95% confidence interval for mean*		*Minimum*	*Maximum*
				Lower bound	*Upper bound*		
Group I	17	3.88 ± 2.01	0.49	2.85	4.91	1.06	6.43
Group II	12*	1.10 ± 1.80	0.52	−0.05	2.24	0.06	6.34
Group III	17	1.07 ± 0.99	0.24	0.56	1.59	0.11	3.15
Group IV	17	4.53 ± 1.95	0.47	3.53	5.54	0.82	7.57
Group V	17	5.40 ± 2.51	0.61	4.11	6.69	2.50	10.93

*Five specimens debonded during storage and were excluded

Table 4: Intergroup comparison of mode of failure

Groups	*Mode of failure*			
	Adhesive failure	*Cohesive failure*	*Mixed failure*	*Enamel failure*
Group I	0	70.59	29.41	0
Group II	0	75	25	0
Group III	0	70.59	29.41	0
Group IV	0	100	0	0
Group V	0	94.12	5.88	0

higher enamel bond strength, and no refrigeration needed as it has higher hydrolytic stability. It also exhibits higher bond strength with metals, zirconia, and alumina. Upon polymerization, the blend of SBU components provides more hydrophobic properties and a high degree of conversion. Before curing and during the application, SBU is hydrophilic, which helps in optimum wetting of the tooth structure. SBU becomes hydrophobic after drying and curing, which helps in providing a long-lasting bond. According to manufacturers, SBU is tolerant to slight/moderate saliva contamination prior to adhesive application.[8]

It is important to provide sufficient thinning of the bonding agent coat while using adhesive systems and sealant together because its thickness can affect the adhesion quality. Upon shrinkage, forces are created which tend to pull the adhesive away from the tooth substrate. Therefore, a thin adhesive layer would help to minimize dimensional changes during polymerization.[17] In the present study, irrespective of the curing protocol (individual or simultaneous light curing), the bonding agent was thinned slightly with a gentle air stream according to the manufacturer's recommendations. Furthermore, as UA infiltration is enhanced if the active application is used,[18] the same was employed in the present study.

The most frequently used tests are the knife-edge test or a lapping shear test; a notch effect at the knife-edge tip should be taken into consideration.[19]

The outcome of these *in vitro* tests depends on several factors, such as:

- Tooth structure (enamel vs dentin).
- The bonding protocol.
- Sample fabrication.
- Material handling.
- Testing parameters.
- Specimen handling.
- Specimen storage.
- Operator skill.[20]

While conducting the present study, utmost care was taken to control and standardize all the above-mentioned factors. The teeth were sectioned to obtain the buccal and lingual surfaces so as to allow the shearing forces to be exactly perpendicular to the bonded specimens.[21] According to ISO standards, prismatic enamel use is recommended.[11] Therefore, surface preparation of the enamel specimen was carried out in the present study as enamel preparation results in smooth surfaces. Additionally, the resultant larger area, in turn, facilitates the adaptation of the mold to the specimen surface. Enamel preparation also eliminates the noncrystalline hypermineralized enamel that could interfere with resin penetration, formation of resin tags, and, subsequently, the bonding.[22] The SBS of the bonded specimen is directly related to the surface area between the test material and the tooth surface.[21] The larger the CS area, the SBS values will be lower. The CS diameter of the specimens was standardized to 3 mm, and standardized Teflon molds (3 mm diameter × 2 mm height) were used to prepare the specimens.[21] The average accepted SBS values range clinically—5.9–7.8 MPa and laboratory performance—4.9 MPa.[6] In the present study, only group V met the suggested criteria for a minimum mean bond strength value of 4.9 MPa under laboratory conditions.

The findings of the present research are in agreement with previous ones that have reported that pre-etching using phosphoric acid, followed by the application of an intermediate adhesive layer, is beneficial and helps in optimizing sealant bond strength.[2,16]

Self-etch (SE) adhesives require a shorter time and fewer steps in application; hence it is claimed as convenient and less technique sensitive.[23] However, in the present study, groups II and III (EWS applied in conjunction with SBU in SE mode) demonstrated significantly lower SBS values than groups IV and V (EWS applied in conjunction with SBU in ER mode).

The lower SBS values exhibited by SE primers could be due to the absorption of water when compared to TE system.

Additionally, TE systems have been reported to have minor gaps and higher bond strengths.[24] In a systematic review of the bond strength of UA in laboratory studies, many studies reported weak enamel bond strengths for UA without pre-etching using phosphoric acid. Though pre-etching using phosphoric acid before application of UA has been suggested to obtain optimal enamel bonding, some studies have reported evidence to the contrary.[25] Therefore, further research is recommended to establish whether UA or other adhesive systems are superior for enamel bonding regardless of pre-etching using phosphoric acid.

In addition to different bonding protocols, the present study also investigated and compared individual and simultaneous light curing of the intermediate bonding agent and the sealant material. There is limited published data addressing whether individual or simultaneous light curing affects the sealant adhesion to enamel, and the existing data is ambiguous regarding the same.[16,17,26] Simultaneous light curing of the adhesive and the sealant has been recommended by some authors, as combining these steps is thought to be less time-consuming for sealant placement with a reduction in the risk of saliva contamination in children and no detrimental effects on sealant strength.[16] Additionally, the lowered complexity of treatment aids in patient management.[26] The present research did not, however, demonstrate significant differences between the two curing protocols.

In this research, a predominance of cohesive mode of failure was observed for all the test groups. When the interfacial strength of the cement tooth bond is greater than the inherent strength of the material, a higher percentage of cohesive mode of failure will be observed, as suggested by some examiners.[27] Additionally, the predominance of cohesive failure could also be attributed to the fact that the customized Teflon mold was filled only with a sealant which resulted in the intrinsic cohesive failure. This finding has also been made by other researchers.[28] No attempt was made to correspond the SBS and the mode of failure as it has been reported that there is no relationship between the two.[29]

Most of the *in vitro* studies use monotonic tests being tensile, compression, flexural, or shear strength, and these tests are not able to simulate the fatigue that occurs in the mouth. So further testing, which incorporates subjecting the specimens to fatigue, is suggested for better clinical relevance. The present research employed the macro shear testing methodology as it is the most commonly advocated method for testing SBS. However, recent studies have started to focus on micro shear testing methodology, where the bonded CS area is <1 mm^2. The present study did not assess the microtensile bond strength or microleakage. It also did not include scanning electron microscopy analysis that could have provided a greater insight into the adhesive interface.

The evaluation of various parameters, such as the outcome of pre-etching with phosphoric acid, the use of adhesive systems, and using dynamic bond strength testing is desirable and is recommended in future studies. Another limitation of the present research is that the specimens were not exposed to thermocycling, as it is done to simulate the clinical conditions.

However, many previously conducted studies[30] have demonstrated that thermocycling significantly reduces the SBS and can lead to debonding of specimens. Moreover, most of the time, dental restorations are only subjected to small temperature changes. Accordingly, the samples were not exposed to thermocycling in the present study. In the present research study, the samples for SBS were stored in distilled water at 37°C to simulate oral temperature and were tested after 1 week of storage. No attempt was made to examine the effect of specimen aging or of media, such as saliva. Only SBU was used as a bonding agent in the present study; it is possible that other bonding agents and systems will have better outcomes.

Bullet points:

- Embrace WetBond™ (EWS) with SBU in the ER mode of application with individual light curing of the adhesive and sealant demonstrated the highest mean SBS values.
- Embrace WetBond™ (EWS) with SBU in the SE mode of application with individual light curing of the adhesive and sealant demonstrated the lowest mean SBS values.
- A predominance of cohesive failure was observed for all the groups. In addition to cohesive mode of failure, the only other mode of failure observed was mixed.

Conclusion

In view of the results and within the restraints of the present research, it can be summarized that EWS with SBU in the ER mode of application can be used as an alternative to a conventional technique for sealant placement for improving interfacial bond strength.

Manufacturer Name

Embrace Wetbond™ (EWS) PF sealant—Pulpdent TM Corporation.

LOT—190115

Scotchbond™ Universal Adhesive (SBU) (commercially available as Single Bond Universal in Asia-Pacific region): 3M ESPE, Saint Paul, Minnesota, United States of America.

LOT—81219C

Etch-Rite TM—Pulpdent TM Corporation.

LOT—190110

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