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Research article

Comparative evaluation of bonding performance between universal and self-etch adhesives: *In vitro* study

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ABSTRACT

Objective: This work aimed to assess the bonding performance of universal adhesive and self-etch adhesives, and a comparative study was conducted using the same acid etching mode.
Methods: The selective acid-etching mode was used to simulate bonded restorations to teeth defects of isolated human molars including enamel and dentin. Microtensile bond strength and microleakage of all adhesives were tested and compared after 24 h and 5000 thermocycles, respectively. The morphology of the adhesive interfaces was observed by scanning electron microscopy (SEM) and fluorescent staining.
Results: The bond strength and microleakage of Single Bond Universal (SBU) adhesive are comparable to those of self-etch adhesives, although Clearfil Tri-S Bond (S3) exhibited significantly lower bond strength compared to other two self-etch groups evaluated. No significant differences were found in the microleakage resistance of these four adhesives, suggesting their similar effectiveness in sealing the margins of the restorations, although SBU showed the highest resistance of microleakage. The SEM and fluorescent staining results of the resin-dentin interfaces further revealed the formation of abundant resin tags for all adhesives.
Conclusions: Self-etch adhesives evaluated in this study performed similarly to universal adhesives in selective acid-etch mode for bond strength and microleakage resistance. Both types of adhesives exhibited effective penetration capabilities into the dentinal tubules.
Clinical significance: During the adhesion processes involving both dentin and enamel, self-etch adhesives can serve as alternatives to universal adhesives in selective acid-etch mode.

1. Introduction

Dental bonding techniques have been innovated and improved with the development of adhesives. The developed bonding adhesives have been classified in a variety of ways, leading to the multiple use of dental adhesives in clinical applications. Etch-and-rinse, self-etch, as well as so-called “universal” bonding systems are widely applied [1–3]. The primary distinction among these bonding systems is their interaction with tooth hard tissue, as well as their simplicity and efficiency in clinical operations. Although etch-and-rinse adhesives are known for the superior bonding strength, their practicality is limited due to the intricate steps required for applications and the increased risk of the post-treatment sensitivity [1].

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Self-etch adhesives, especially in one-step formulations, simplify the bonding process by eliminating the need for a separate etching step [4,5]. One-step self-etch adhesives combine etchant, primer, and adhesive functionalities, using etching acids that can simultaneously remove the smear layer and penetrate dentin micropores [6,7]. Although these adhesives are formulated with lower pH levels to reduce tooth erosion, they typically have a higher pH than conventional etchants [6]. However, their weaker bond strength with enamel requires an additional etching step for optimal enamel adhesion. This approach, known as selective-etch, has emerged as an effective strategy for dental bonding, highlighting the need for tailored application techniques to maximize adhesive performance [8–11].

In order to overcome the limitations of previous generations, universal adhesives are designed to provide a bonding solution that simplifies clinical procedures without compromising bond strength. These adhesives are formulated to facilitate bonding to a diverse range of restorative substrates, such as resin composites and metals [9,12]. Several commercial formulations, such as Single Bond Universal (3M ESPE), Adhese Universal (Ivoclar Vivadent), CLEARFIL Universal Bond Quick (Kuraray), and All-Bond Universal (Bisco), exemplify this advancement [5]. Similar to self-etch adhesives, universal adhesives are able to etch and penetrate enamel and dentin surfaces. This process, which incorporates both micromechanical anchoring and chemical bonding mechanisms, enhances the bond strength and durability between the adhesive and tooth structures. The presence of acidic monomers plays a critical role in enabling simultaneous etching and penetration, which effectively advances the bonding process [6].

In self-etch and universal adhesives, the most widely used monomer is 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), which forms ionic bonds with Ca^{2+} of hydroxyapatite (HAp) through its phosphate/carboxyl groups. In addition, 10-MDP provides a more stable and effective bond in aqueous environments compared to other monomers [9,13,14]. Despite the greater versatility of universal adhesives compared to the self-etch ones, there is a lack of comprehensive comparative analysis of their performance, particularly in terms of bond strength and microleakage through thermocycling aging. Therefore, investigations into the performance of these adhesives under consistent etching procedures are essential to evaluate their durability.

The purpose of this present work was to assess the application performance of four different commercial adhesives through *in vitro* testing, including one universal adhesive and three one-step self-etch adhesives. The evaluation focused on assessing bond strength and microleakage using the same bonding mode, where thermocycling was applied to simulate long-term durability of adhesion and microleakage. The penetration of the adhesive into dentinal tubules was characterized by their interfacial morphologies. The first null hypothesis was that the universal adhesive would significantly surpass the self-etch adhesives in terms of bond strength and durability to dentin and enamel. The second null hypothesis was that the universal adhesive would be significantly more effective in resisting microleakage than the self-etch ones.

2. Materials and methods

2.1. Materials

In this study, the third molars were gathered, which was approved by the Ethics Committee of Yantai Stomatology Hospital (approval number: 2021–11). Prior to tooth collection, informed consent was obtained from all individuals, confirming their voluntary participation and understanding of the study's purpose. Four commercial dental adhesives were selected, including Single Bond Universal (SBU, 3M ESPE, USA), Adper Easy One (AEO, 3M ESPE, USA), Clearfil Tri-S Bond (S3, Kuraray, Japan), and BeautiBond (BB, Shofu, Japan). The detailed description of these materials and their handling procedures are collected in Table 1. According to the

Table 1
Compositions and handling procedures of commercial dental adhesives according to the manufacturer's instructions.

Material	Category	Composition	Handling procedures
Single Bond Universal (SBU, 3M ESPE, USA)	Universal adhesive	MDP, dimethacrylate resins, HEMA, Vitrebond™ copolymer, filler, ethanol, water, initiators, silane	1 Apply the adhesive to the prepared tooth and rub for 20 s after selective enamel etching. 2 Air dry for 5 s. 3 Light cure with LED unit (1000 mW/cm^2) for 10 s.
Adper Easy One (AEO, 3M ESPE, USA)	One-step self-etch adhesive	MHP, dimethacrylate resins, HEMA, Vitrebond™ copolymer, filler, ethanol, water, initiators	1 Apply the adhesive to the prepared tooth and rub for 20 s after selective enamel etching. 2 Blow gently for 5 s. 3 Polymerize with light for 10 s.
Clearfil Tri-S Bond (S3, Kuraray, Japan)		10-MDP, HEMA, Bis-GMA, water, ethanol, silanized colloidal silica, camphorquinone	1 Following the selective enamel etch, apply the adhesive to the prepared tooth and leave for 20 s. 2 Dry under high-pressure for 5 s. 3 Cure with light for 10 s.
BeautiBond (BB, Shofu, Japan)		Acetone, distilled water, Bis-GMA, carboxylic acid monomer, TEGDMA, phosphonic acid monomer and others	1 Following the selective enamel etch, apply the adhesive to the prepared tooth and leave for 10 s. 2 Dry under high-pressure for 5 s. 3 Cure with light for 10 s.

Abbreviations: HEMA: 2-hydroxyethyl methacrylate, MHP: methacryloxyhexyl phosphate, Bis-GMA: bisphenol-A-glycidyl methacrylate, and TEGDMA: triethyleneglycol dimethacrylate.

product instructions, a light-curing lamp with a wavelength range of 400~500 nm was used.

2.2. Teeth preparation

The teeth were carefully screened to ensure the oral health status and the absence of any signs of dental caries or decay. To guarantee the accuracy and reliability of the experimental results, only those that met the criteria were chosen. The teeth were then stored in 0.5 % Chloramine T solution at 4 °C after the removal of pulps and the solution was changed daily. These teeth were used within six months [15].

2.3. Micro-tensile bond strength test

2.3.1. Bonding procedure

Universal adhesive or one-step self-etch adhesive was applied to bond the resin composite and enamel or dentin according to the manufacturer's instructions (Table 1). Eighty caries-free teeth were selected and randomized into eight groups ($n = 10$) to test bond strength of four different adhesives on enamel or dentin. Flat enamel or dentin surfaces were exposed with a water-irrigated low-speed diamond saw (SYJ-150, Kejing, China) and then grinded with SiC paper (600#) to form a standardized smear layer. Each group were further randomized into two subgroups ($n = 5$) for the bond strength tests after soaking in water for 24 h or thermocycling, respectively.

For the enamel-bonded samples, the enamel surfaces were pre-etched following the selective etch protocol. Specifically, the enamel was etched with 35 % phosphoric acid gel (Gluma, Kulzer GmbH, Germany) for 20 s, followed by the water spray for 10 s and the air spray for 5 s. Adhesives were then applied and light-cured according to the manufacturer's instructions (Table 1). Commercial dental composite (Filtek™ Z350 XT Universal Restorative, shade A3, 3M ESPE, USA) was selected to create build-ups of 5 mm in diameter and 4 mm in height on the bonded surfaces. Layer filling method was used and each layer did not exceed 2 mm in thickness. Meanwhile, each step was polymerized for 20 s with a curing light (LED55N, light intensity: 1000 mW/cm^2, TPC, USA). All procedures were performed at 23 ± 2 °C. Subsequently, the obtained samples were immersed in distilled water for 24 h at 37 °C.

For dentin-bonded samples, the pre-etching step was omitted and dentin treatments were achieved through the self-etch function of different adhesives (Table 1).

2.3.2. Thermocycling

The thermocycling procedure referred to previous studies [16–18] and ISO 11405 [15]. Following water storage for 24 h, one subgroup of the samples ($n = 5$) underwent 5000 thermal cycles in distilled water. The alternating temperatures were set at 5 and 55 °C with a dwell time of 20 s and a transfer time of 5 s at each temperature.

2.3.3. Test procedure

The micro-tensile test procedure for bonding strength was based on ISO 11405 [15]. After water storage for 24 h or thermocycling, the samples were cut into beam-shape with a cross section of 1 mm × 1 mm in size. The specimens ($n = 3$) from each sample were randomly selected and a total of 15 specimens from each group were tested. The microtensile bond strength of these samples was measured with a microtensile tester (T-61010K, Bisco, USA).

2.3.4. Statistical analysis

The bond strength values were analyzed by a two-way for repeated measures ANOVA (between-subject factor: adhesive and within-subject factor: storage time) and the Tukey's test. Statistical significance is defined as $*p < 0.05$, whereas $**p < 0.01$ and $***p < 0.001$ indicate highly significant difference and extremely significant difference, respectively.

2.4. In vitro microleakage test

The *in vitro* microleakage test of the adhesives between resin composites and teeth structure, including enamel and dentine, was also performed based on ISO 11405 [15]. Similar to previous studies [19], the margin sealing of four dental adhesive systems was compared by microleakage of the stain at the edges of the restoratives. The selective acid etching mode was used to simulate the restoration of dental cavities.

2.4.1. Specimen preparation

Eighty teeth were carefully chosen and inspected to ensure the absence of fractures or carious lesions. Each one was treated with a high-speed handpiece containing an air-water spray. A high-speed diamond bur was used to create a circular Class V cavity on the buccal surfaces with a width of 3 mm and a depth of approximately 1 mm into the dentin, positioned at the junction between dentin and enamel. The treated teeth were then randomly assigned into four groups ($n = 20$). All cavities were treated with the selective etching procedure. As described in section 2.3.1, the exposed enamel was etched for 20 s with a 35 % phosphoric acid gel, followed by thorough rinsing and drying. The adhesives were then applied and light-cured following the handling procedures in Table 1. The cavities were filled with Z350 XT using the layer filling method. The layered resin composite was then cured in the cavity using a light-curing unit as described in section 2.3.1. Each composite layer, with a maximum thickness of 2 mm, was cured for 20 s individually to ensure adequate polymerization. The restorative surfaces were polished with Sof-Lex flexible discs after restoration. Each group was further divided into two subgroups (n = 10) to undergo either short-term or thermocycling tests.

2.4.2. *Thermocycling*

The thermocycling protocol was performed as described in section 2.3.2. Briefly, each subgroup (n = 10) underwent 5000 thermal cycles in water bath set at 5 and 55 °C, respectively.

2.4.3. *Assessment of microleakage*

After either a 24 h water bath or thermocycling, each tooth surface was coated with two layers of nail varnish, applied 1 mm from the edge of the restoration. After the nail varnish cured, the teeth were immersed in a 0.5 % alkaline magenta dye solution at 23 °C for 24 h, followed by a thorough rinse. The specimens were then embedded in auto-polymerizing and marked accordingly. To allow longitudinal examination of the teeth block, a low-speed, water-cooled diamond disk was employed to cut along both sides of the midline of the restorations. Three sections were obtained from each block. The examination of all sections was performed with a stereomicroscope (10 ×) to assess the extent of microleakage surrounding the restorations.

The standardized scoring system was used to evaluate the degree of marginal leakage [20]. That is, 0 degree, indicating no leakage; 1 degree, denoting leakage up to half the length of the cavity wall; 2 degree, signifying leakage through the entire wall of the cavity, excluding the cavity root; and 3 degree, representing leakage along through the entire wall of the cavity, as well as the cavity root.

2.4.4. *Statistical analysis*

Experimental data were statistically analyzed by Kruskal-Wallis, Mann-Whitney *U* test, and Wilcoxon signed rank test. The significance level was set at $p < 0.05$.

2.5. *Interfacial morphology*

Sixteen teeth were prepared and divided into four groups corresponding to the different adhesives tested. The specimens were further divided into two subgroups (n = 2) for SEM and laser confocal observations. Following the sample preparation technique described in Section 2.4.1 for the microleakage tests, Class V cavities were prepared on the buccal surface of the tooth. After etching the enamel, adhesives were applied and the restorations were filled. Subsequently, sections of the tooth block were sliced to obtain restoration and dentin bonding specimens. The interfacial morphology of bonding specimens was examined using SEM and confocal laser scanning microscope (CLSM) after fluorescent staining, according to the previous report [21].

2.5.1. *SEM observation*

The samples were sliced and polished with a series of silicon carbide papers (P600, P800, P1000, and P1200) under water irrigation. The obtained slices were subjected to H_3PO_4 (37 %) for 15 s, followed by washing thoroughly. To deproteinize the specimens, NaClO solution (2 %) was applied for 120 s, followed by ethanol solutions (50, 70, 95, and 100 % vol%). The specimens were then sputter-coated with gold film and visualized through an SEM (S4800, Hitachi, Japan) at 2000 × magnification.

2.5.2. *CLSM examination*

Fluorescent staining required the pre-addition of fluorescent dyes to the bonding agent to facilitate color development during tests, as reported previously [21,22]. Therefore, dental adhesives were firstly mixed with Rhodamine B (0.1 wt%), and the following operation was the same as the preparation of dentin slices. The obtained specimens were inspected by a CLSM (CLSM800, ZEISS, Germany) where the emission fluorescence was recorded at 570–590 nm.

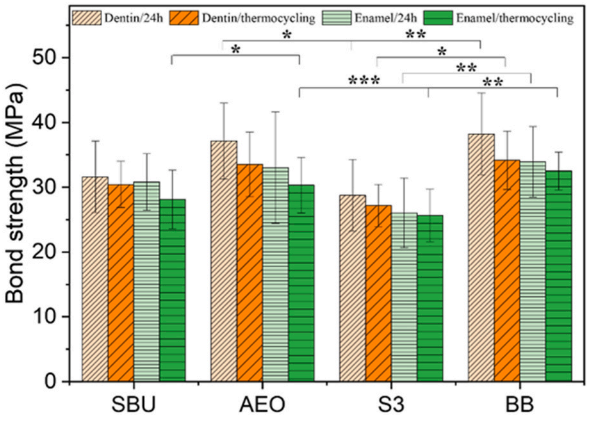

Fig. 1. Bond strength of the studied dental adhesives to enamel and dentin with or without thermocycling.

3. Results

3.1. Bond strength

The microtensile bond strength of various adhesive systems was measured to compare their bonding properties. As observed in Fig. 1, S3 showed the lowest bond strength for both dentin and enamel at 24 h (28.75 ± 5.53 MPa and 27.18 ± 3.25 MPa, respectively), which was significantly different from AEO and BB. Those two self-etch adhesives achieved the highest initial bond strengths to both dentin and enamel, although a decline was found after 5000 thermocycles. The universal adhesive SBU demonstrated competitive performance with a mean initial bond strength of 31.59 ± 5.51 MPa for dentin and 30.44 ± 3.56 MPa for enamel. However, SBU and the other self-etch adhesives did not exhibit significant differences in bond strength, except for a significantly lower value on enamel compared to AEO. After thermocycling, the bond strength of all evaluated adhesives showed a reduction trend in both dentin and enamel. There was no statistically significant difference in bond strength before and after thermocycling, despite some variability indicated by the standard deviations.

3.2. Microleakage

Figs. 2 and 3 display the microleakage of the representative samples of the four adhesives, highlighting the penetration of the red dye. The corresponding microleakage scores of these adhesives are presented in Tables 2 and 3. These results indicated that the dye penetration occurred on both occlusal and gingival sides, where degree 0 was frequently observed (Figs. 2A and 3A), although the microleakage on the occlusal side was slightly lower than that of the gingival margin. Dye penetration is more likely to occur at the adhesive interface and infiltrates between the layers of the composite restorative (Fig. 2B). In some cases, the dye penetration could cease at the interface between the enamel and dentin (Fig. 2C and D), or at the end of the cavity wall (Fig. 3B and D). Among all materials with or without thermocycling, only S3 received a score of 3, indicating that the dye was penetrated to the cavity root (Fig. 3C). Although this adhesive exhibited more severe microleakage, its mean microleakage score did not exceed degree 1 (Table 3), suggesting its effective margin sealing for restorative purposes. Notably, the SBU group displayed overall a low to negligible microleakage by comparison to the other three self-etch groups. Furthermore, the microleakage of all studied adhesives after thermocycling was slightly worse than that without thermocycling. However, the microleakage scores were not significantly different between these four adhesive groups under both conditions.

3.3. Interfacial morphology

The representative views of interfacial morphology and resin tag formation into the dentin substrate under SEM and CLSM are shown in Fig. 4. It was clear that each bonding adhesive formed resin tags by infiltrating dentinal tubules, but the ability to penetrate varied among these adhesives. Among all materials, SBU produced long, dense, and uniform resin tags that penetrated deeply into the tubules and formed a tight interfacial bond (Fig. 4A1 and A2). BB behaved similar but slightly sparser compared to SBU (Fig. 4D1 and D2). AEO formed numerous and evenly distributed resin tags, but most were short and penetrated less in depth into dentinal tubules (Fig. 4B1 and B2). However, the resin tags formed by S3 had the characteristics of varying thickness and length (Fig. 4C1 and C2). Although no obvious hybrid layers were observed in SEM images, the fluorescence staining results indicated that each adhesive formed a thin resin-dentin interface.

4. Discussion

Dental adhesives are designed to bond the restoration to teeth in order to seal the margins and prevent leakage. Interfacial gaps can cause microleakage, resulting in teeth discoloration, secondary caries and potential pulp irritation [19,23]. Adhesives are capable to resist shrinkage of the resin composite and maintain a durable bond while bonding resin to teeth [16,23–25]. Therefore, bonding

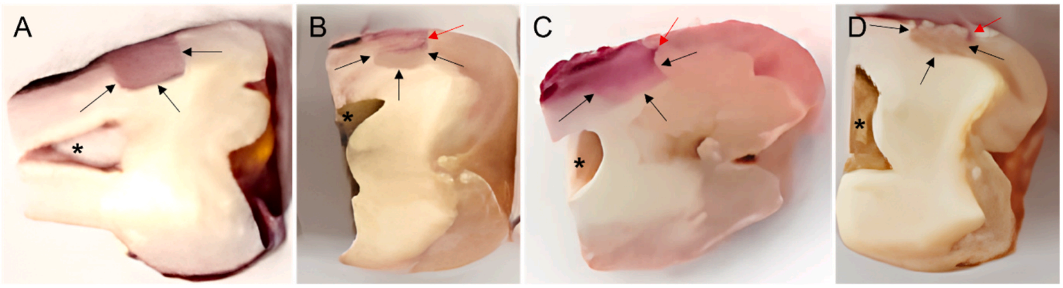

Fig. 2. Digital images of the microleakage evaluation of four adhesives without thermocycling: SBU (A), AEO (B), S3 (C), and BB (D). The black arrows indicate the edges of the restorations, the red arrows point to the marginal microleakage, and the asterisks represent the pulp cavity located on the gingival side.

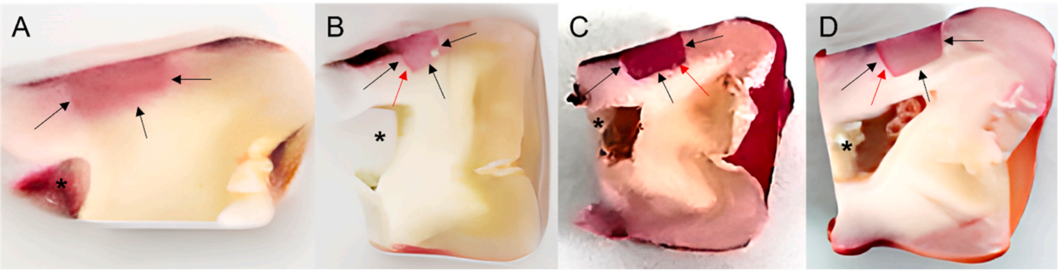

Fig. 3. Digital images of the microleakage evaluation of four adhesives with thermocycling: SBU (A), AEO (B), S3 (C), and BB (D). The black arrows indicate the edges of the restorations, the red arrows point to the marginal microleakage, and the asterisks represent the pulp cavity located on the gingival side.

Table 2
Microleakage scores of the four adhesives without thermocycling.

Material	Occlusal margin					Gingival margin				
	0	1	2	3	Mean	0	1	2	3	Mean
SBU	8	2	0	0	0.2	7	3	0	0	0.3
AEO	6	4	0	0	0.4	6	3	1	0	0.5
S3	6	3	1	0	0.5	6	3	1	0	0.5
BB	7	3	0	0	0.3	6	4	0	0	0.4

Table 3
Microleakage scores of the four adhesives with thermocycling.

Material	Occlusal margin					Gingival margin				
	0	1	2	3	Mean	0	1	2	3	Mean
SBU	7	3	0	0	0.3	7	1	2	0	0.5
AEO	5	3	2	0	0.7	6	2	2	0	0.6
S3	5	2	2	1	0.9	6	1	3	0	0.7
BB	5	4	1	0	0.6	6	2	2	0	0.6

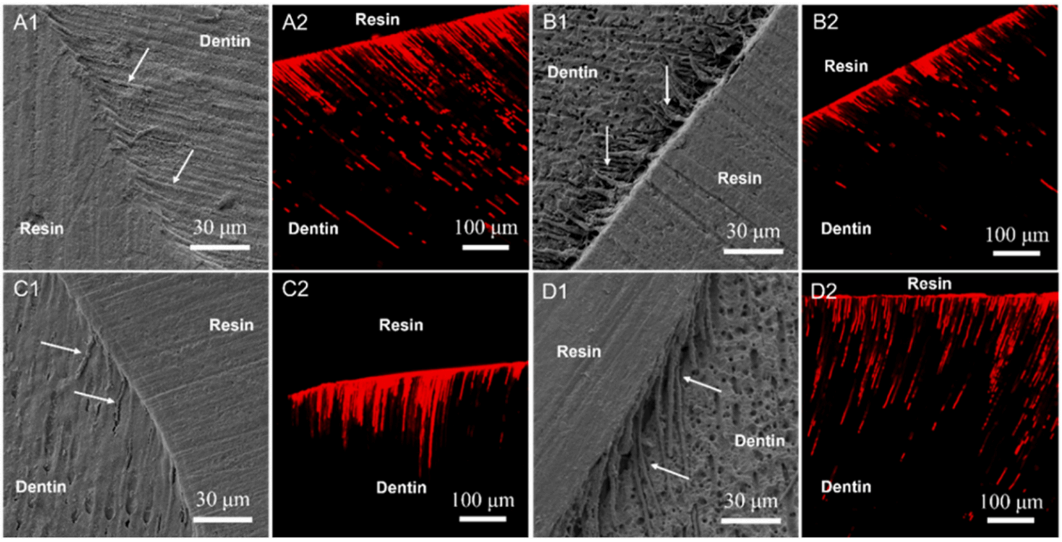

Fig. 4. SEM images (A1-D1) and CLSM micrographs (A2-D2) of the resin-dentin interface. SBU (A1, A2), AEO (B1, B2), S3 (C1, C2), and BB (D1, D2). White arrows in (A1-D1) represent resin tags.

strength and margin sealing are the two most important properties of adhesives.

Universal adhesive has emerged as an improvement due to its extensive application. Both universal and self-etch adhesives provide similar bonding properties under the same operation condition [2,26]. This similarity can be explained by the presence of functional phosphate monomer in these adhesives, particularly 10-MDP, which possesses the acid etching function [9,26,27]. The four adhesives investigated in this study are composed of a blend of cross-linking, acidic, and hydrophilic monomers, as well as water, organic solvents, and fillers, which are integrated into a unified system. However, there are slight differences in the compositions of these adhesives. AEO is an early self-etch adhesive product of 3M ESPE, with MHP as the acidic monomer [28]. In the developments of subsequent products, the acidic monomer in SBU was replaced by 10-MDP.Apart from the acidic monomer MDP, both S3 and SBU incorporate HEMA as an amphiphilic monomer and employ ethanol as the solvent, resulting in compositional similarities. In contrast, BB has a unique formulation that is HEMA-free and utilizes phosphonic and carboxylic monomers which favor a strong bond to dental tissue after their *in-situ* polymerization, as specified by the manufacturer's specifications [29]. These adhesives exhibit similar acid etching capacity for dentin due to the honeycomb tubular structure in the self-etch mode. However, providing sufficient acid etching effect on enamel is still challenging for these adhesives due to the dense crystalline structure of enamel [6]. Despite this, acid etching is a widely used technique for surface roughening of enamel and enhancing adhesion to enamel. In fact, previous studies have reported that a significant higher bond strength can be achieved by pre-acid etching [9,26,30–32], which is attributed to the creation of a rough enamel surface, leading to the micromechanical retention. This protocol of pre-acid etching is also known as selective acid etching mode.

Previous studies have investigated different etching methods for self-etch adhesives in recent years. Currently, mild acidity is the common recognition of self-etch adhesives, and the bond strength was significantly enhanced by enamel preparation via the acid etching before application [33–36]. Poggio et al. also came to the similar conclusion that one-step self-etch adhesives should produce improved bond strength when enamel was pre-etched [37]. Therefore, the selective acid etching protocol serves as an appropriate approach to assess the performance of both universal and self-etch adhesives.

The micro-tensile testing method was used in this study since it could be performed on the small-sized samples, allowing more accurate results [38,39]. Although 500 thermal cycles are required by ISO 11405, we performed 5000 thermal cycles instead to ensure a more rigorous evaluation. Due to the dietary habits, the oral temperature fluctuations can affect the performance of dental adhesives. Based on previous studies, 5000 thermal cycles were applied to simulate approximately six months of accelerated aging to predict the long-term behavior of adhesives [40,41]. The first null hypothesis was rejected, as the universal adhesive SBU did not exhibit the highest bond strength and was not significantly different from other three self-etch adhesives studied (Fig. 1). This result implies that self-etch adhesives can also exhibit high bonding performance in case of enamel pre-acid etching. It is important to note that SBU and S3, which both contain 10-MDP, showed only slight decreases in dentin bonding strength after thermocycling. This finding highlights the importance of 10-MDP in preserving the bonding durability. Regarding to the enamel bonding, no obvious degradation in strength after thermocycling was observed, suggesting that pre-etching enamel contributes to the increased bonding stability.

The marginal sealing is crucial for ensuring the stability between the restoration and dental tissues. The microleakage test can provide a direct reflection of the sealing effectiveness of adhesives. Furthermore, the micro-morphology of the interface could reveal the interactions between the adhesive and dentin, which helped to understand how these adhesives achieve interfacial bonding and the margin sealing [42,43]. Both SEM and CLSM results demonstrated visually good penetration of all adhesives (Fig. 4). The SBU and BB groups showed extensive resin-dentin interfacial contact and longer resin tags (Fig. 4A1, A2 and D1, D2). In contrast, the AEO and S3 groups produced shorter but fairly uniform and fine resin tags (Fig. 4B1, B2 and C1, C2). All adhesives provided high bond strength due to their resin tags that penetrate into the dentin to form a strong mechanical locking effect. Compared universal adhesives with self-etch groups in self-etch mode, similar quantities of resin tags and thicknesses of mixed layers were observed (Fig. 4A2-D2). These above results suggested that the studied two types of adhesives exhibited similar bonding behavior. In addition, the penetration of adhesives into dentin structure helps to form margin sealing, as confirmed by microleakage experiments (Figs. 2 and 3).

Furthermore, there was no significant correlation between bond strength and microleakage, which was consistent with previous studies [43,44]. The microleakage results (Tables 2 and 3) indicated that SBU exhibited better marginal sealing followed by BB. While AEO and S3 provided effective sealing with no significant difference compared to SBU, the second null hypothesis was rejected. This could be attributed to the inclusion of phosphate monomer, that facilitated the formation of a strong and stable phosphate-Ca salt through chemical interaction with HAp crystals of the dental tissue [6,45,46]. Although additional acid etching operations are generally not required when applying self-etch adhesives, it can raise concerns about insufficient bond strength. The shallow etching of enamel surface by acidic monomer and the decrease in micromechanical retention are the main reasons [33,47]. These factors have the potential to adversely influence the bond strength and the durability of the adhesive materials, resulting in the margin leakage and even secondary caries. This present work demonstrates the self-etch adhesives studied achieves bond strength and margin sealing comparable to the universal adhesive in the selective acid etching mode. This present work selected only three one-step self-etch adhesives and one universal adhesive, which may limit the generalizability of the findings. Other types of bonding systems, such as etch-and-rinse adhesives, and different bonding modalities were not evaluated. Furthermore, the study focused on the microtensile bond strength and the microleakage, different methods of examination are also highly needed to provide a more comprehensive evaluation of the adhesive performance.

5. Conclusions

In this work, the selected three self-etch adhesives exhibited comparable bond strengths and microleakage resistance to the universal adhesive, which also showed potential long-term durability and adequate penetration into dentinal tubules. In the selective etching mode, self-etch adhesives are considered the potential replacement to universal adhesives.

Ethics statement

This study was approved by the Ethics Committee of Yantai Stomatology Hospital with the approval number: 2021–11.

Data availability statement

The data presented in this study have not been deposited into a publicly available repository. The data will be available on reasonable request from the corresponding authors.

CRediT authorship contribution statement

Zhiwei Ren: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Ruili Wang:** Writing – review & editing, Supervision, Methodology, Investigation. **Meifang Zhu:** Writing – review & editing, Supervision, Project administration, Investigation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Meifang Zhu reports financial support was provided by National Key Research and Development Program of China. The authors would like to thank Dr. Hongyan Chen (Donghua University, Shanghai, China) for her contributions in the experimental work. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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