〔Review〕

A Review of the Strength Properties of Currently Available Adhesive Systems used in Orthodontic Practice

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Abstract

Resin based adhesive systems are an integral part of orthodontics and esthetic dentistry. Over the years, there has been an exponential increase in the use of resin based adhesive systems leading to the introduction of multiple newer generations of these materials. However, there is a lack of evidence based data comparing the clinical efficacy of these resin based systems. This literature review aims to compare the strength properties of conventional etch−and−rinse adhesive systems with that of the newer self−etch adhesive systems in orthodontic bracket cementation. The article discusses laboratory tests like shear and tensile bond strength tests, adhesive remnant index (ARI), scanning electron microscope (SEM) examination of enamel−adhesive interface and the effect of water, saliva or blood contamination at different stages of adhesive application. The adhesives discussed in this article are : Transbond XT, Transbond Plus, Transbond MIP, Clearfil Mega bond, Clearfil Protect Bond, Clearfil S3 Bond and Kurasper F by Kuraray ; BeautyOrtho−bond by Shofu ; G−Premio Bond by GC ; Orthomite Super−bond by Sunmedical ; Biscem DC and All−bond Universal by Bisco Dental ; AdheSE and Esthetic LC by Ivoclar−Vivadent ; Aegis Ortho by Bosworth Co., iBond Universal by Kulzer Intl., Breeze adhesive by Pentron ; C&B Metabond by Parkell ; Assure by Reliance Orthodontic Products ; Rely−a−bond, RelyX Unicem, Adper Prompt L−pop and Scotchbond Universal by 3M ; Enlight by Ormco ; OptiBond FL by Kerr Dental. Each system has its strengths and weaknesses and by comparing the mechanical as well as strength properties, prospective and current researchers as well as orthodontic practitioners will be able to perceive an overall perspective on which resin based adhesive system performs better in which clinical condition.

Introduction

The basic requirements for a bracket−bonding system are to obtain an acceptably high bond strength between the orthodontic brackets and enamel and a low failure rate, as loose brackets delay the treatment and replacing them is inefficient, time−consuming and not economical. Several better adhesive systems have been developed till now, owing to the rapid advancement in technology. At present, 4 basic bonding systems are commercially available ; i) Conventional etch−and−rinse adhesives ii) self−etch adhesives iii) universal adhesives and iv) resin based glass ionomer adhesives. Generation wise ; the etch−and−rinse adhesives, also referred to as total−etch adhesives fall into 4th and 5th generations while the self−etch adhesives belong to 6th, 7th and 8th generations. Based on the mechanism of adhesion, adhesives are classified into 4 types : i) three−step including etch, prime and bond ii) two−step including etch followed by prime−bond together iii) two−step including etch−prime together followed by bond iv) one−step incorporating etch−prime−bond all in one solution. That leads to 2 formulations of primer solution, one is conventional and the other one is self−etch type. Acidic monomers in self−etch systems simultaneously etch and prime the tooth surface. This simplified approach can provide clinically more reliable performance (Sofan et al.). Yet there is insufficient in–vitro as well as clinical research that can conclude on a firm note regarding the overall comparison between conventional acid–etch and self–etch bonding systems. Concerns have been raised about the bonding effectiveness of different self–etch systems related to their durability (Sofan et al.). The adhesion of resin to enamel is affected by the orthodontic force from arch–wire as well. Occlusal force, may also lessen the bond strength as they cause shearing force at the resin–enamel and resin–bracket interfaces (Mohammadi et al.). For this reason, the initial bond strength of orthodontic brackets is important since many orthodontists activate appliances in the mouth at the same day of bracket bonding and the bond strength of resin adhesive increases with time due to continued polymerization of the resin under the bracket base (Ching et al.). The adhesive containing self–etch primer is well accepted due to its fewer steps, simple clinical application and reduced technique sensitivity (Shakya et al.). There are inevitable limitations of universal bonding systems as well ; for example, the bonding efficacy of both total–etch and self–etch prime and bond solutions to universal adhesives are hampered by the intrinsic permeability of these simplified systems to water that increases the higher chance of bond failure. Also, the hybrid layer is liable to water sorption and subsequent reduction in mechanical properties (Eliades et al.). Orthodontists around the globe still use conventional and self–etch adhesive systems (King et al.). The traditional etch–and–rinse adhesives manifest much higher bond strength than any other type of adhesives because of the phosphoric acid which creates micro–roughness on the etched enamel surface and aids in stronger bond between the adhesive and enamel. But self–etch primer has the great advantage of accelerating the bonding procedure by combining etching and priming into a single step (Yonekura et al.). They also minimize the potential for iatrogenic damage to enamel other than saving time and reducing procedural errors. Their lower etching ability is caused by a relatively less acidic pH as compared with different concentrations of phosphoric acid used in conventional etch–and–rinse systems (Yonekura et al.). In recent years, a substantive number of studies have been done focusing on brackets, adhesive systems and enamel surface conditioning methods. Therefore, the aims of this review were to :

A. Discuss the properties of different adhesive systems and provide an evidence–based data of their merits and demerits.

B. Compare the bond strength between conventional etch–and–rinse technique and self–etch technique and review their clinical performance when used with conventional, self–etch and universal adhesives.

Methodology

A review of the literature was performed by using electronic and hand–searching methods regarding the bond strength properties of resin based adhesive systems in orthodontic bracket bonding. Only in–vitro studies were selected from October 2000 to June 2018.

Shear bond strength

Shear bond strength (SBS) is the most significant measure for a good orthodontic bracket bonding, as it withstands a varying range of forces during orthodontic treatment. It can be explained by the resistance of adhesives against the shear sliding force (along the direction of the jaws) applied to the orthodontic brackets (Mohammadi et al.). Mohammadi et al. observed the shear bond strength of chemically–cured and light–cured conventional etch–and–rinse bonding agent. In both cases, bond strength increased along with increasing force due to the continued polymerization reaction. The results of the experiment of Meerbeek et al. indicated that the manner of preparation of enamel (cleaning and polishing of enamel surface) prior to bonding procedures significantly influenced the bonding effectiveness of both etch–and–rinse and self–etch adhesives. Yonekura et al. examined the SBS of an etch–and–rinse adhesive, OptiBond FL and a self–etch adhesive, Clearfil SE. The combination of thermocycling (a laboratory test to simulate aging in oral environment) and a torsion load significantly decreased the mean SBS for the specimen bonded with the etch–and–rinse adhesive system, which indicates that the torsion load contributed to degradation of this system. For self–etch adhesive system there was no significant difference in the mean SBS between specimens thermocycled with and without a torsion load. Iijima et al. also evaluated the SBS of etch–and–rinse Transbond XT and self–etch Transbond Plus and BeautyOrtho–bond and concluded that Transbond Plus and Transbond XT showed higher average bond strength values (9.75 MPa and 9.14 MPa respectively) in dry condition than BeautyOrtho–bond (6.74 MPa). However, in wet condition, Transbond XT exhibited poor SBS (1.47 MPa) compared to Transbond Plus and BeautyOrtho–bond (7.74 MPa and 7.62 MPa respectively). It is noteworthy that orthodontic brackets and tubes are intended to be bonded to teeth with an adhesive material for a limited time only. Therefore, an appropriate bond strength would serve to ease the debonding procedure and decrease the risk of enamel fracture (Iijima et al.). In the comparison between etch–and–rinse and self–etch adhesives by Saleh et al. it was concluded that the SBS values of brackets cemented with Transbond etch–and–rinse (18.6 MPa) were significantly higher than those of the four self–etch adhesives : Esthetic cement system, Rely X, Biscem DC and Breeze. Vilchis et al. compared the SBS of 5 different kinds of adhesive systems and found out that etch–and–rinse Transbond XT and self–etch Transbond Plus promoted higher SBS values (19.0 MPa and 16.6 MPa respectively) than the other self–etch adhesives : Clearfil Mega Bond, Ortho–bond and AdheSE. An interesting study by Nakazawa et al. found no significant difference among the three self–etch adhesives ORTHOPHIA LC, BeautyOrtho–bond, Transbond Plus and one universal adhesive Super–Bond C&B (with conventional etch–and–rinse technique). However, the SBS of Super–Bond C&B (17.5 MPa) was significantly higher than all self–etch adhesives. Another study by Abdelnaby et al. detected the highest SBS in Transbond XT adhesive, with and without torsion load (11.2 MPa and 10.7 MPa respectively) among the four adhesives they experimented on. Saito et al. experimented on a universal adhesive Super–Bond C&B and found no significant difference between total–etch and self–etch technique in dry condition. But SBS decreased notably in etch–and–rinse technique after samples had been immersed in water or thermocycled. Yet, Oz et al. found that etching the enamel with phosphoric acid significantly improved bond strengths of universal adhesives Scotchbond Universal and All–bond Universal compared to self–etching technique, but storage time did not significantly affect bond strengths. Katona et al. tested different strengths of bonding adhesives : in shear stress, traditional etch–and–rinse produced a stronger bond than the self–etch. Even so, when tested in tension, the etch–and–rinse bond was weaker than the self–etch bond ; and when tested in torsion, the bond strengths were similar. Yamamoto et al. compared the SBS among conventional (Transbond XT and Kurasper F), self–etch (Transbond Plus and BeautyOrtho–bond) and universal (Super–Bond Ortholite) adhesives on different follow–up times (5,10,60 minutes and 24 hours) and came to a summary that all materials had the highest bond strength values at 24 hours. The comprehensive comparison of shear bond strength values from all the reviewed studies is shown in Table.

Efficacy of etching

The fundamental mechanism for adhesion of bonding

Table 1 : Shear bond strength of different adhesive systems

Researchers	Materials	Follow up period and condition	Result (mean MPa)
Yonekura et al., 2011	***Dry condition***	Thermocycling	
	Transbond XT [etch & rinse]	[6000 cycles] with torsional load	8.9
	Transbond Plus self–etching primer (SEP)	1･45N/cm	8.4
	Beauty Ortho bond [SEP]		6.1
Iijima et al., 2008	***Dry condition***	24 hours	
	Transbond XT [etch & rinse]	in 37 c water	9.75
	Tranbond Plus SEP		9.14
	Beauty Ortho bond [SEP]		6.74
	Wet condition		
	Transbond XT [etch and rinse]		1.47
	Transbond Plus SEP		7.74
	Beauty Ortho bond [SEP]		7.62
Saleh et al., 2010	***Dry condition***	24 hours	
	Transbond XT [etch & rinse]		18.6
	Esthetic cement system [SEP]		6.0
	Rely X [SEP]		6.0
	Biscem DC [SEP]		2.2
	Breeze [SEP]		8.4
ScougallVilchis et al., 2007	***Dry condition***	24 hours in 37 c water	
	Transbond XT [etch & rinse]		19.0
	Transbond Plus SEP		16.6
	Clearfil Mega Bond FA [SEP]		11.0
	Shofu Primer A and B [SEP]		10.1
	AdheSE [SEP]		11.8

Abdelnaby et al., 2010	***Dry condition***	24 hours in 37 c water	
	Transbond XT [etch & rinse]		11.2
	Rely–a–bond [etch & rinse+ universal]		8.8
	Transbond Plus SEP		7.8
	RelyX Unicem [SEP+ universal]		5.8
Rodríguez Chávez et al., 2013	***Dry condition***	24 hours in 37 c water	
	Transbond MIP [etch & rinse]		6.8
	Transbond Plus SEP		6.1
Iijima et al., 2010	***Dry condition***	24 hours in 37 c water	
	C&B Metabond [SEP+ universal]		11.6
	Transbond Plus SEP		8.8
Zeppieri et al., 2003	***Dry condition***	24 hours in 37 c water	
	Transbond XT [etch & rinse]		21.3
	Transbond MIP [etch & rinse]		20.7
	Transbond MIP, then wet, again Transbond MIP		13.1
	Transbond Plus SEP		13.7
	Transbond Plus SEP, then wet, again Transbond Plus SEP		13.8
	Wet condition		
	Transbond MIP		15.0
	Transbond MIP, then wet, again Transbond MIP		14.9
	Transbond Plus SEP		12.7
	Transbond Plus SEP, then wet, again Transbond Plus SEP		13.6
Yusua et al., 2009	***Dry condition***	2 years or thermocycling [6000 cycles]	
	Transbond XT [etch & rinse]		9.8
	Transbond Plus SEP		9.1
	Beauty Ortho bond [SEP]		7.4
Cacciafesta et al., 2003	***Dry condition***	24 hours in 37 c water	
	Transbond XT [etch & rinse]		11.95
	Transbond MIP		12.76
	Transbond Plus SEP		12.29
	Wet condition		
	Transbond XT [etch & rinse]		4.54
	Transbond MIP [etch & rinse]		8.01
	Transbond Plus SEP		10.87
Öztoprak et al., 2007	***Dry condition***	72 hours in 37 c water	
	Transbond XT [etch and rinse]		15.28
	Transbond Plus SEP		13.76
	Assure hydrophilic primer		16.40
	Saliva contamination		
	Transbond XT [etch and rinse]		3.79
	Transbond Plus SEP		13.80
	Assure hydrophilic primer		10.66
	Blood contamination		
	Transbond XT [etch and rinse]		3.08
	Transbond Plus SEP		5.28
	Assure hydrophilic primer		6.83
Turk et al., 2008	***Dry condition***	Thermocycling	
	Transbond XT [etch and rinse]	0 cycle	18.08
		2000 cycles	17.14
		5000 cycles	16.70
	Transbond Plus SEP	0 cycles	18.15
		2000 cycles	14.50
		5000 cycles	14.68

agent to enamel is resin penetration into the enamel surface. Etching enamel surface is crucial because this creates micro–porosities on the surface of enamel by exposing enamel prisms. Afterwards, the resin monomers penetrate into the etched surface of enamel which micro–mechanically bond through the surface resin tags upon polymerization (Sofan et al.). Iijima et al. examined the interface between the adhesive resins (Transbond XT, Transbond Plus and BeautyOrtho–bond) and enamel through scanning electron microscopy (SEM) to evaluate the etching depth of the adhesives. SEM

Minicket al., 2009	***Dry condition***		
	Aegis Ortho [SEP+ universal]	30 minutes	5.31
	Clearfil Protect Bond [SEP+ universal]		7.05
	iBond [SEP+ universal]		3.91
	Clearfil S3 Bond [SEP+ universal]		3.80
	Transbond XT [etch and rinse]	24 hours in 37 c water	10.05
	Aegis Ortho [SEP+ universal]		7.17
	Clearfil Protect Bond [SEP+ universal]		6.09
	iBond [SEP+ universal]		3.86
	Clearfil S3 Bond [SEP+ universal]		6.60
	Transbond XT [etch and rinse]		10.11
Turk et al., 2007	Transbond Plus SEP	24 hours	
	• Dry condition		17.61
	• Saliva contamination after priming		10.94
	• Saliva contamination before priming		10.05
	• Saliva contamination before and after priming		9.79
Otsby et al., 2008	***Dry condition***	30 minutes	
	Transbond XT [etch and rinse]		4.2
	Adper Prompt L–Pop [SEP]		5.9
	Clearfil Mega bond [SEP+ universal]		6.5
Arhun et al., 2006	***Dry condition***	48 hours in deionized water	
	Adper Prompt L–Pop [SEP]		9.62
	Clearfil Protect Bond [SEP+ universal]		13.85
	Transbond Plus SEP		6.39

showed that the resin penetration depth of self–etch adhesives into intact enamel was very shallow (0.5 μm or less) due to mild etching effect. In comparison, the micro resin tags were longer in etch–and–rinse adhesive (7 to 10 μm). In addition, self–etch primers had relatively less acidic pH values (1.89 and 2.20) while 35% phosphoric acid showed the strongest etching effect on enamel due to relatively stronger acidic pH value (1.39). Also, according to Pamir et al., phosphoric acid etching led to higher bond strength between the adhesive and tooth enamel, due to its ability to create micro–porous enamel surface more efficiently.

Adhesive remnant index

Adhesive remnant index (ARI) is a functional measure of the strength between adhesive and the surface of enamel. It can be measured in different scales according to experiment design and can be calculated from the quantity of material retained on the enamel surface after debonding of the adhesive. The more residual adhesive that remains on the enamel surface after debonding, the stronger bond there is between the adhesive and enamel (Mohammadi et al.). Meerbeek et al. experimented on etch–and–rinse type (OptiBond FL) and self–etch type (Clearfil SE) adhesive and concluded from their ARI scores that different magnitudes of bonding force had significantly different failure modes in each adhesive group. The failure area shifted from bracket–adhesive interface to the adhesive–enamel interface with heavier bonding force. Another study obtained ARI scores of two different types of bonding systems (etch–and–rinse Transbond XT ; self–etch Transbond Plus and BeautyOrtho–bond), both in dry and wet conditions. They found a significant difference in wet condition. Transbond etch–and–rinse adhesive retained no material on the enamel surface in 91.7% of the teeth. Contrarily, both self–etch adhesives, Transbond Plus and BeautyOrtho–bond had all or more than 90% material remaining in 75% of the teeth. This result supports their SBS test result that found Transbond XT performing stronger than the self–etch adhesives in dry condition but much poorer than self–etch types in wet conditions (Iijima et al.). Vilchis et al. reported BeautyOrtho–bond as the weakest adhesive (compared to etch–and–rinse Transbond XT, self–etch Transbond Plus, universal Clearfil Mega Bond and AdheSE), 51.4% of the sample of which had no residual adhesive after debonding ; and 48.5% had less than half of the adhesive left on the tooth surface. On the other hand, Transbond XT showed the highest ARI scores : 40% of the teeth retained all adhesive with a distinct impression of the bracket mesh while 48.5% retained less than half. In another study by Hosein et al. there was a significant difference in the ARI scores between etch–and–rinse Transbond XT and self–etch Transbond Plus adhesive, with more adhesive remaining on the enamel surface in the etch–and–rinse group. However, another study by Chavez et al. reported no significant difference between the ARI scores of self–etch adhesive Transbond Plus and moisture－insensitive adhesive Transbond MIP ; neither after 1 hour nor after 24 hours. In both groups, 66.7% of the samples retained less than half of the adhesive after 24 hours of followup while after 1 hour of followup, 33.3% and 40.0% sample retained more than half adhesive in Transbond MIP and Transbond Plus respectively.

Enamel surface and color modification

Acidity of the etching agent, either as a separate solution or incorporated in primer, is an important determinant for enamel surface change that is caused by application of these solutions. Strong acidic solutions with lower pH values (values below 7.0 exhibit acidic properties) create micro porosities on the surface of enamel by exposing the enamel prisms (Sofan et al.). Iijima et al. measured the pH between 35% phosphoric acid and Transbond plus, BeautyOrtho−bond self−etch primers and found that the pH for phosphoric acid was 1.39 compared to 1.85 for Transbond Plus and 2.20 for BeautyOrtho−bond. Both self−etch primers with relatively less acidic pH values had a milder etching effect on intact enamel. Contrarily, 35% phosphoric acid showed the strongest etching effect for intact enamel as expected with its relatively stronger acidic pH value. In case of enamel color alteration, it is caused not only by the residues of resin tags in enamel, but also by a host of other factors such as clean−up method (grinding and polishing using bars and discs) at the time of bracket removal. The study by Hosein et al. suggested that enamel loss with a self−etch primer was significantly less than conventional etching with 37% phosphoric acid and the greatest enamel loss was seen after conventional etching (−1.11 to −4.57 μm) and least with the use of the self−etch primer (−0.03 to −0.74 μm). Based on the study by Bishara et al. the lower etching abilities of self−etch bonding systems minimized the potential for iatrogenic damage to enamel. Pashley et al. used three self−etch primers with different pH values : Clearfil Mega Bond (Kuraray) with pH 2.0, Non−Rinse Conditioner (Dentsply) with pH 1.2 and Prompt L−Pop (3M) with pH 1.0 in their study. It was found that the etching patterns of aprismatic enamel were dependent on the aggressiveness of the acids, but there was no correlation between the degree of aggressiveness of etchants and the bond strength of adhesives to intact enamel. However, the findings of this study are debatable, considering they used self−etch primers that had stronger acidic pH values than one of the conventional phosphoric acid concentrations, 35% (1.39). Ireland et al. also reported more enamel loss when teeth were etched with 37% phosphoric acid, compared to using self−etch primer.

Effect of saliva contamination and thermocycling

To simulate aging method as in clinical environment, the most common method is thermocycling (TC) which has been widely used to investigate bracket bond strength (Shakya et al.). In this experiment, samples are exposed to cyclic thermal fluctuations to simulate one of the many factors in the oral environment affecting bond strength laboratory tests. The degradation mechanism that occurs near an adhesive during water storage (WS) tests is thought to be mainly related to the hydrolytic degradation of the adhesive (Sfondrini et al.). TC tests, however, can accelerate degradation near the adhesive layers due to thermal stress ; this is because of both the discrepancies between the thermal expansion rates of the substrates and the hydrolytic degradation caused by the water bath (De Munck et al.). In the study by Iijima et al. the adhesive systems were evaluated by contamination with saliva. The etch−and−rinse adhesive Transbond XT exhibited such a significantly low SBS value (1.47 MPa) that it would not be clinically acceptable. By contrast, SBS of self−etch adhesives Transbond Plus and BeautyOrtho−bond (7.74 and 7.62 MPa respectively) were not adversely affected by saliva contamination. Interestingly, to simulate the exact clinical conditions where ideal isolation is often difficult during bracket bonding, Nakazawa et al. submerged their sample groups water for 24 hours followed by thermocycling and found no significant difference between the bond strength of self−etch adhesives ORTHOPHIA LC, BeautyOrtho−bond, Transbond Plus and etch−and−rinse adhesive Super−Bond C&B. Other studies by Zeppieri et al. and Yusua et al. found that saliva had no effect on the bond strength of the Transbond self−etch system while Schaneveldt et al. reported after examining the moisture−insensitive primers Assure (Reliance Orthodontic Products) and Transbond MIP (3M) that moisture contamination decreased SBS if occurred before application of the first layer in both primers. However, according to Cacciafesta et al. and Öztoprak et al. water, saliva and blood contamination caused significant decrease in SBS of the conventional and hydrophilic primers, yet self−etch primer was least affected by saliva contamination. So, contamination of enamel with saliva after priming decreased the bond strength although it was still clinically adequate. As for universal adhesive systems, Suzuki et al. experimented with Scotchbond Universal, G–Premio Bond and All Bond Universal and found that they were not affected by water contamination (both thermocycled group and 3–months, 6–months, 1–year and 2–years water–stored group). Nevertheless, Cartas et al. examined the action of alcoholic beverage on bonding agents and detected that bonding strength varied with the type of solution used, either experimental solution or actual beverage. In the experimental solution which imitated alcohol, universal adhesive Enlight was stronger than conventional Transbond XT while it was opposite in rum.

Conclusion

Looking into all the studies reviewed it is evident that there is a clear difference between conventional etch–and–rinse bonding systems and self–etch bonding systems in terms of bond strength. In dry condition, the etch–and–rinse adhesives exhibit better bond strength between adhesive–enamel interface compared to the self–etch adhesives. However, the same adhesives fail drastically in wet contaminated condition. Phosphoric acid of etch–and–rinse adhesives results in stronger etching of enamel surface than the mild etching caused by the self–etch adhesives, but causes substantial loss to enamel surface. However, the result of ARI analysis is significantly different in dry and wet condition. Regarding the bond strength against water, a few studies found no significant difference between dry or wet condition. But some studies found low SBS in both etch–and–rinse adhesives and moisture–insensitive adhesives especially when contamination occurred before and/or after priming. Yet self–etch adhesives are least affected by saliva contamination. In the reviewers' opinion, conventional acid–etch bonding agents are better in overall strength outcomes as long as the tooth surface remains dry.

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