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COMPARISON OF SHEAR BOND STRENGTH OF BRACKETS BONDED WITH FOUR DIFFERENT BONDING PROTOCOLS AT DIFFERENT TIME INTERVALS; AN IN VITRO STUDY

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Keywords:
Shear bond strength, Orthodontic adhesives, Self-adhesive, Thermocycling, Aging, Self-etch self-adhesive, Adhesive remnant index

Abstract:

Objective: *To test shear bond strength and mode of debonding of brackets bonded using a traditional orthodontic adhesive (Transbond XT), self- adhesive material (Heliosit) and self-etch &self-adhesive resin material (Vertise flow) with and without phosphoric acid etching; after 15 minutes, 24 hours and following aging and thermocycling.*

Materials and Methods:
One hundred and eighty upper first premolar teeth were used in this study. The specimens were equally and randomly allocated into four groups. TXT group (Transbond XT; n=45); HS group (Heliosit group; n=45); VF group (Vertise Flow; n=45) and (VF+P) (Vertise Flow with phosphoric acid etch; n=45). Each group was randomly divided into three equal subgroups; First subgroup (n=15) shear bond strength was tested after 15 minutes of bracket bonding, second subgroup (n=15): shear bond strength was tested after storage in distilled water at 37°C for 24 hours and third subgroup (n=15): shear bond strength was tested after specimens storage in distilled water at 37°C for 6 weeks and subjected to 1000 thermal cycles. Adhesive remnant index (ARI) was recorded for each specimen and its mean was compared between different groups.

Results: *Vertise flow (either with or without enamel pre-etching) and Transbond had acceptable bond strength at 15minutes debond testing. Heliosit adhesive had a significantly lower SBS at 15 minutes debond. Transbond XT had a significantly higher (SBS) compared to the other 3 groups at 24 hours debond. Thermocycling and aging conditions affected SBS in all the groups except specimens bonded using Transbond XT. Vertise Flow when used without enamel pre-etch resulted in decreased SBS below the clinically acceptable value after thermocycling and aging.*

Conclusions: *Both Vertise Flow (when used with pre-etched enamel) and Heliosit can be used in orthodontic practice, offering simplified bonding procedures associated with clinically acceptable bond strength and minimal amount of remaining adhesive on enamel surface at debond.*

Introduction

Buonocore [1], in 1955 proposed that acid etch could be implemented before adhesive resin application for surface treatment which marks the start of the era of adhesive dentistry. Afterwards, Newman [2] introduced the concept of bonding of orthodontic brackets and subsequently various bonding adhesives were developed. This marks the introduction of the concept of direct bonding in orthodontics. Rapid revolutionized trials in material science

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over the years have produced progressively advanced material, making the direct bonding procedure more precise, comfortable, and time effective.

Several overlapped systems of classification have been proposed. They mainly differ in modes of application of the solutions and the components and chemistry inherent to a particular material. Although three-step etch-and rinse systems were considered as a huge leap in adhesive dentistry, the search for more simple adhesive systems has led to these developments: two-step self-etch systems which combine conditioning and priming functions in a single bottle; and all-in-one adhesive systems which combine all the three functions in a single bottle

The main objective of contemporary adhesive system manufacturers is to develop bonding agents that offer the fastest, simplest and best quality of bonding. However, with any kind of steps reduction in clinical application procedure, a concern in decrease of bonding strength usually arises. [3] The bond strength of the orthodontic bracket must be able to withstand the forces applied during the orthodontic treatment. 5.9–7.8 MPa resistances were suggested as an acceptable range for orthodontic bonding. [4]

In addition to technique simplicity with reduced number of steps, issues with etched enamel contamination in uncooperative patients and leaving etched enamel surface unprotected with adhesive layer are completely eliminated.[5]

Various studies had shown that flowable composites showed comparable shear bond strengths to Transbond XT and were suggested as promising materials for orthodontic bracket bonding. [6, 7]

Helioset (Ivoclar Vivadent) was introduced as a highly transparent stable and convenient orthodontic adhesive that can be used for metal and ceramic brackets without prior priming either on the bracket base or etched enamel surface. The monomer consists of urethane dimethacrylate, Bis-GMA and decandiol dimethacrylate . The filler consists of a highly dispersed silicon dioxide. Manufacture claims reported bonding strength of 12 MPa with metal brackets. [8]

When comparing Heliosit Orthodontic with Transbond XT, studies concluded that Transbond XT showed higher bond strengths in all the studies. Nevertheless, the bond strengths of Heliosit for orthodontic bonding were in the clinically acceptable range. [9-12]

Vertise Flow (Kerr, Orange, CA, USA) is a self-etch self-adhesive flowable resin composite. It was introduced to the market as an adhesive-free restorative material indicated for the restoration of small Class I and V cavities, for repairing porcelain chips, as a liner for large restorations, and as a pit and fissure sealant.

Though, Vertise flow achieved early bracket shear bond strength (SBS) similar to conventional adhesive even without prior enamel conditioning. Following thermocycling, Vertise flow with and without etching manifested a significant decrease in SBS with different pattern of residual remnant. [13]

Since bonding efficacy [13, 14], mechanical properties after aging [15] and type of failures after debonding [16] are critical factors for orthodontists when selecting an orthodontic adhesive, the aim of this study was to evaluate the shear bond strengths (SBSs) and adhesive remnant index (ARI) of self-adhesive resin material (Heliosit) and self-etch &self-adhesive composite (Vertise flow) and compare them to a traditional orthodontic adhesive (Transbond XT).

PICO model

P: Metal orthodontic brackets bonded to upper first premolar teeth

I: Orthodontic adhesives with simplified application; *self-adhesive resin* (enamel etch + no bonding agent + adhesive), *self-etch self-adhesive resin* (with or without enamel etching + no bonding agent + adhesive)

C: Compare the used adhesives to each other and to a control *Transbond adhesive* (enamel etch + bonding agent + adhesive)

O: Bond strength in MPa

The null hypothesis of this study was:

There would be no statistically significant differences in SBS and ARI between a traditional orthodontic adhesive, self- adhesive material, and self-etch self-adhesive resin material with and without phosphoric acid etching at different testing-time intervals.

Materials and Methods

Tooth specimens:

One hundred and eighty upper first premolar teeth extracted for orthodontic purposes were used in this study. Teeth with obvious enamel hypoplasia, fractures, or caries were excluded.

The specimens were given random numbers. The specimens were randomly and equally allocated (www.random.org) into four groups 45 specimens each.

Pre-bonding preparation:

After eliminating all soft tissue remnants, the teeth were cleaned and pumiced by using a rubber cup with slurry of non-flouridated paste in a slow hand-piece for 15 seconds. These were then thoroughly washed with distilled water and air-dried with oil and moisture-free air source till desiccation.

A maxillary first premolar metallic bracket (Gemini 3m Unitek, Monrovia,Calif) was bonded to the buccal surface of each premolar. Bracket base area and mesh size provided by the manufacturer was 9.82 mm^2.

It was not possible to blind the operators to the bonding system being used because the systems had different forms of application. Standardization was achieved by bonding all the brackets in the same sitting by the same operator. (Figure 1&2)

In TXT group, (Transbond XT group; n=45); Bonding was performed using Transbond XT light cure adhesive. Ivoclar Etching Gel was applied to teeth on the middle third of the buccal surface surfaces for 30 seconds, rinsed with water and gently air dried thoroughly. Thin uniform coat of primer was applied on each tooth surface to be bonded and cured for 10 seconds. Transbond XT adhesive paste was applied with a syringe onto bracket base. The brackets were lightly placed onto teeth surfaces and adjusted at the center of the buccal surface of the teeth and pressed firmly to seat the bracket and was light cured for 20 seconds according to manufacturer's instruction.

In HS group, (Heliosit group; n=45**);** Bonding was performed using Heliosit Orthodontic adhesive (IVOCLAR VIVADENT) that contains primer and adhesive in 1 syringe. The teeth were conditioned Ivoclar Etching Gel for 30 seconds, washed with water and dried to frosty white appearance. The single-component Heliosit Orthodontic (Ivoclar Vivadent AG) bonding material was applied to the under surface of the brackets. Brackets were then light-cured as in group 1.

In (VF) group,(Vertise Flow; n=45)**;** Vertise Flow (Kerr, Orange, CA, USA) which is a self-etch self-adhesive resin material, was applied on enamel surfaces, and bracket bases were bonded in place without separate enamel etching step before bonding. This flowable composite was light-cured using LED for 20 second each on both mesial and distal sides (i.e., 40 s total).

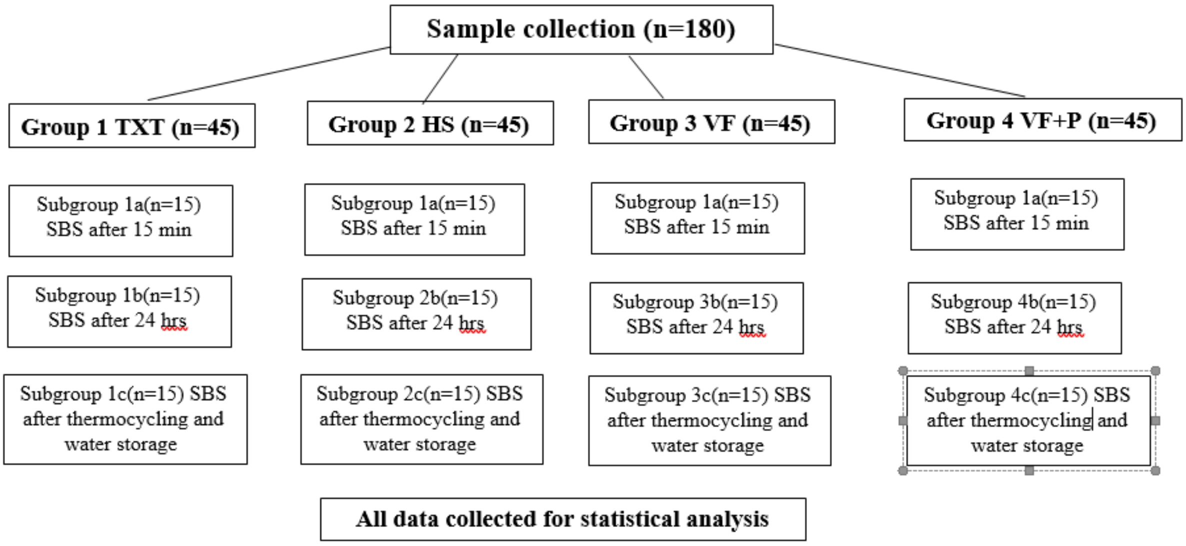
In (VF+P) group, (VF with phosphoric acid etching; n=45); Enamel etching procedure was performed as that for TXT group. After VF was applied on enamel surfaces and bracket bases were bonded in place, flowable composite was light-cured using LED for 20 s each on both mesial and distal sides (i.e., 40 s total).

Each group was randomly divided into three equal subgroups:

First subgroup (n=15 per group): shear bond strength was tested after 15 minutes of bracket bonding.

Second subgroup(n=15 per group): After bracket bonding procedure, all specimens were stored in distilled water at 37°C for 24 hours followed by shear bond strength test.

Third subgroup(n=15 per group): Following bracket bonding and distilled water storage at 37°C for 6 weeks, the specimens were then subjected to 1000 thermal cycles between 5-55°C with a dwell time of 30 seconds.



In the current study, aging was performed by water storage for 6 weeks and thermocycling between 5-55°C for 1000 cycles. Thermocycling accelerates the process of aging and water diffusion. (17-19)

Figure 1:Brackets bonded and mounted in acrylic mold.

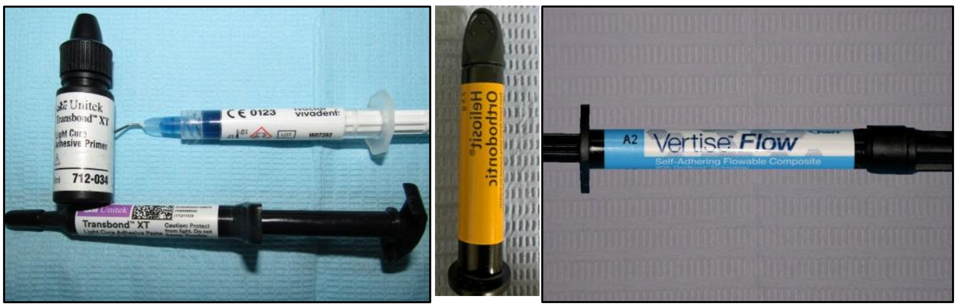


Figure 2: Bonding adhesives used in the study

Shear bond strength test

A 0.017 x 0.025-in stainless steel wire was ligated into each bracket slot to reduce any deformation of the bracket during debonding. The teeth were fixed in acrylic resin, and a mounting jig was used to align the facial surface of the tooth to be parallel to the force during the Shear bond strength test.

Shear bond strength (SBS) of each group was measured using a universal testing machine (Biomaterial department, Faculty of Dentistry, Alexandria University) at a crosshead speed of 1 mm/min.

Shear force was applied parallel to the long axis of each tooth. (Figure 3)The force required to shear off the bracket was directly recorded in Newtons (N) and converted into megapascal (MPa) using the following equation:

Shear force (MPa) =Debonding force (N)/Bracket surface area (mm^2) where 1 MPa=1 N/mm^2.

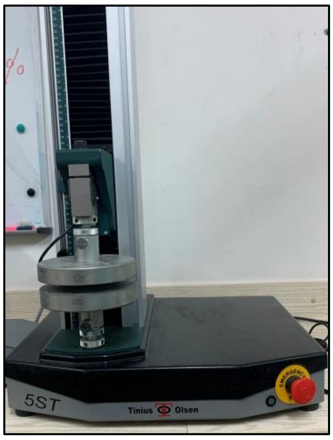


Figure 3: Universal testing machine

After debonding, each specimen was examined under a stereomicroscope (Biomaterial department, Faculty of Dentistry, Alexandria University) to identify the mode of the bond failure. (Figure 4) The residual composite remaining on the tooth surface was evaluated by using the remnant index (ARI), where each specimen will be scored according to the following; [20]

Score 1 = 100% adhesive remnant left on the enamel surface.

Score 2 = more than 90% adhesive remnant left on the enamel surface.

Score 3 = 10-90% adhesive remnants left on the enamel surface.

Score 4 = less than 10% adhesive remnant left on the enamel surface.

Score 5 = no adhesive remnant left on the enamel surface.

Figure 4: Stereomicroscope used in the study

Statistical analysis:

For intra-examiner reliability in the ARI scoring, all specimens were scored again after 2 weeks by the same author. ARI scores recorded in the second session were exactly the same as those recorded in the first session.

Statistical analysis was performed using SPSS 15 (Statistical Package for the Social Sciences, SPSS Inc, Chicago, USA).

Normality of data distribution was assessed using Kolmogorov–Smirnov test. The statistical differences in bond strength between specimens debonded at 15min, after 24h and following aging and thermocycling was assessed with the independent t-test in each group.

Distribution of the adhesive remnant index (ARI) score between different bonding materials used and between different debonding times and conditions were analyzed with Kruskal–Wallis non-parametric test, followed by Mann–Whitney test for pairwise comparisons. Significance level was set to α= 0.05 at all the analyses.

One-way analysis of variance was executed on the shear bond strength data measured at 15 min, after 24h and after aging and thermocycling among the four study groups. The Tukey test was used for post hoc comparisons when significant differences were detected.

Results

The descriptive statistics of the shear bond strength (SBS) values for the specimens debonded at 15 minutes for different study group is shown in table 1. No statistically significant differences were found between the study groups except the Heliosit adhesive which had a significantly lower SBS at 15 minutes debond when compared to the other test groups.

Table 1: Descriptive statistics of mean shear bond strength (in MPa) of the four study groups at 15 minutes debond.

Group	N	Mean SBS	SD	Significance (P<0.05)
TXT	15	6.6	2.3	A
HS	15	3.5	1.1	B
VF	15	5.8	1.9	A
VF+P	15	6.2	2.8	A

*Different letters denote significant differences between study groups.

The descriptive statistics of (SBS) values for the specimens debonded after 24 hours and the specimens debonded after being subjected to aging factors are shown in table 2 and table 3 respectively. The specimens debonded after 24 hours showed no statistically significant deference in the SBS between the different study groups except the specimens bonded using transbond XT which had a significantly higher (SBS) compared to the other 3 groups. However, the specimens debonded after being subjected to aging factors showed significant difference in SBS values between different groups except between groups (HS) and (VF+P) where SBS showed no statistically significant differences. Both groups had an intermediate SBS lying between the highest SBS achieved from TXT and the lowest SBS achieved from VF without phosphoric acid etch

Table 2: Descriptive statistics of SBS (in MPa) of the four study groups at 24 hours debond.

Group	N	Mean SBS	SD	Significance ($P<0.05$)
TXT	**15**	**13.8**	**3.2**	**A**
HS	**15**	**10.4**	**2.8**	**B**
VF	**15**	**10.6**	**2.6**	**B**
VF+P	**15**	**11.1**	**3.2**	**B**

In the “Significance” column, different letters label statistical significance between-group differences.

Table 3: Descriptive statistics of SBS (in MPa) of the four study groups after being subjected to aging and thermocycling conditions before debond.

Group	N	Mean SBS	SD	Significance ($P<0.05$)
TXT	**15**	**12.2**	**2.6**	**A**
HS	**15**	**6.2**	**3.1**	**B**
VF	**15**	**3.1**	**1.6**	**C**
VF+P	**15**	**6.8**	**2.2**	**B**

In the “Significance” column, different letters label statistical significance between-group differences.

In table 4, the descriptive statistics of SBS of the four study groups at different testing periods is illustrated. Shear bond strength significantly increased after 24 hours in all the study groups, where HS showed the highest increase in SBS after 24 hours. Thermocycling and aging conditions affected SBS in all the groups except specimens bonded using TXT, where no statistically significant difference in SBS was detected after thermocycling and aging. Thermocycling and aging had a dramatically negative effect on SBS in the specimens bonded using versatile flow with no enamel etching.

Table 4: – Descriptive statistics of SBS (in MPa) of the four study groups according to the established testing periods and aging conditions

Group	Testing periods			
	15 minutes	24 hours	Aging + Thermocycling	Significance (P<0.05)
TXT	6.6^{a}	12.8^{b}	12.2^{b}	P<0.05
HS	3.5^{a}	10.4^{b}	6.2^{c}	P<0.01
VF	5.8^{a}	10.6^{b}	3.1^{c}	P<0.05
VF+P	6.2^{a}	11.8^{b}	6.8^{a}	P<0.05

Different letters denotes statistical significance between groups.

Absolute distribution frequency of the adhesive remnant index is shown in table 5. No samples were assigned to score 1 in any of the study groups at any test period. Only eight samples had composite-free enamel (score 5); most of them in the VF group after thermocycling and aging. (Figure 5)

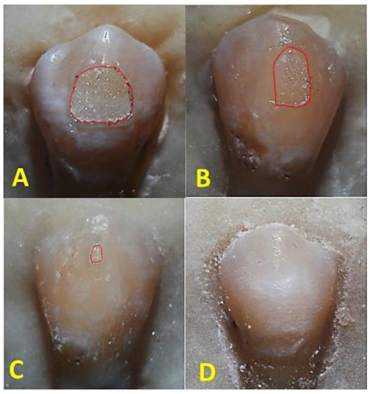


Figure 3: Representative stereomicroscopic photos of specimens showing different ARI scores; A = Score 1 = 100% adhesive remnant left on the tooth; B = Score 3 = 10-90% adhesive remnant left on the tooth; C = Score 4 = less than 10% adhesive remnant left on the tooth; D = Score 5 = no adhesive remnant left on the tooth.

Table 5: Absolute distribution frequency of the adhesive remnant index (ARI). Kruskal–Wallis test with significance level set at 5%.

Group	Testing periods														
	15 minutes					24 hours					Aging + Thermocycling				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
TXT	0	9	6	0	0	0	9	4	2	0	0	8	5	2	0
HS	0	10	5	0	0	0	6	8	1	0	0	1	10	3	1
VF	0	9	4	2	0	0	2	6	7	0	0	1	2	7	5
VF+P	0	6	8	1	0	0	4	9	1	1	0	1	9	4	1

15min: x2(3) = 2.59; p = 0.456; 24 H: x2(3) = 9.892; p = 0.02; Aging+thermocycling: x2(3) = 12.98; p = 0.003; TXT: x2(2) = 0.11; p = 0.946; HS: x2(2) = 11.84; p = 0.003; VF: x2(2) = 9.998; p = 0.004; VF+P: x2(2) = 6.50; p = 0.039.

At 15min debond, most of the specimens had ARI of either score 2 or score 3. Significant differences were observed between the different study groups after 24h (x2(3) = 9.892; p = 0.02) and following thermocycling and aging (x2(3) = 12.98; p = 0.003). Debonding after 24-hour showed an increase in specimens recording ARI (score 4) especially in specimens bonded using versatile flow without pre-etching. Thermocycling and aging also had most of its effect on specimens bonded using versatile flow without enamel pre-etching; where specimens debonded with ARI score 5 started to show in this group exceptionally.

All the groups showed changes in debond failure modes after thermocycling and aging except in the TXT group where almost equal distribution of failure modes were recorded between specimens. Significant differences were observed between the groups HS, VF and VF+P in the ARI score distribution in the different testing periods (HS: x2(2) = 11.84; p = 0.003; VF: x2(2) = 9.998; p = 0.004; VF+P: x2(2) = 6.50; p = 0.039). When enamel was etched with phosphoric acid (groups TXT, HS and VF+P), a greater amount of composite remained on the enamel surface after debonding especially after thermocycling and aging.

Discussion

Bonding procedures are always considered to be one of the most important procedures executed during the journey of orthodontic treatment. Reducing its steps could be helpful for the clinician to reduce chair time and to reduce the possibilities of getting unintended mistakes during this technique sensitive proceudre. Self-etch adhesives have been introduced to reduce the steps needed during the bonding process by omitting the separate etching procedure. In the current study, Heliosit orthodontics composite resin and Vertise Flow flowable composite have been tested. Heliosit orthodontic composite has been marketed to simplify the bonding procedures by omitting the separate adhesive application step; and Vertise flow composite to be a self-etch self-adhesive resin with need for neither separate etching nor bonding steps. The Transbond light cure adhesive has been used as a control where separate etching and bond-application procedures were used before applying the adhesive loaded bracket.

The bond strength of orthodontic brackets is satisfactory clinically when it lies between 5.9 and 7.8 MPa. (4) However, to avoid enamel fractures or chipping during debonding procedures, the bond strength should not exceed the enamel tensile strength (11- 25 MPa). (21)

Clinically, brackets are subjected to forces as early as 10-15 minutes after finishing the bonding procedures, when archwires are inserted and tied into the brackets. (22) This gives the initial bond strength a prime importance. The results of the current study showed satisfactory initial bond strength for all the materials tested except Heliosit. These results comes in agreement with Vinagre et al(23) and Goracci et al.(13) Heliosit adhesive had an initial mean bond strength of 3.5 MPa, which is considered to be below the acceptable clinical limit suggested by Reynolds,(4) and this initial bond strength is signifantly lower when compared to the control group TXT. However, this relatively low initial SBS may be satisfactory clinically as the forces produced from initial archwires are low compared to those applied at a later point in treatment. Enamel etching with phosphoric acid prior to bonding using VF did not seem to significantly affect the bond strength at 15 minutes debond. No significant differences were observed in initial bond strength between the groups VF, VF+P and TXT (the control group). However, the bond strength produced by VF on enamel after 15 minutes considered to be significantly low to what was claimed by the manufacturer; 15 MPa after 15 minutes increasing to reach 22.4 MPa after 24 hours.

Previous studies (24, 25) concluded that composite adhesives reach their maximum strength after 24 hours. Indeed, the results of the current study showed that mean SBS values were doubled after 24h from those obtained at 15min for all adhesive systems used except for HS, where the 24h SBS almost increased 3 times. This doubling in mean SBS comes in agreement with previous studies.(26-28) This could be explained by the slow and gradual diffusion of free radicals that are produced in the resin at the bracket periphery by maximum light exposure to polymerize the remaining resin under the bracket base over time resulting in the increased SBS. (29, 30) After 24h debond, the control group (TXT) had a significantly higher SBS compared to the other study groups, however, no significant differences were observed between the other study groups (HS, VF and VF+P). However, SBS recorded in all the study groups exceeded the recommended range of acceptable clinical bond strength suggested by Reynolds;(4) and was to close to the lower border of the tensile strength of enamel (11- 25 MPa).(21) Again, the results of the current study did not support the VF manufacturer's claims that bonding to enamel can reach 22.4 MPa after 24 hours. Adding a separate pre-etching step prior to using VF did not seem to be effectively affecting the SBS at 24h debond period.

The adhesive between the enamel and the bracket undergoes aging due to being subjected to mechanical, chemical and thermal changes from the oral environment. Experimental aging procedures could simulate these changes to produce similar effects to oral environment in vitro studies.(18,31) Thermocycling is one of the familiar and commonly used aging procedures in the experimental studies to simulate the aging effect produced by water and temperature changes in the oral cavity.

Five hundred cycles in water between 5 and 55°C have been approved by the International Organization for Standardization (ISO) TR 11450 standard (1994) as an appropriate artificial ageing test. However, various studies had increased the number of thermocycling cycles prior to shear bond strength to imitate the long period of orthodontic treatment which ranges between two and three years. (19, 32)

Thermocycling(31) was found to adversely affect the physical and mechanical properties of resin-based materials as well as their bond strength to dental tissues.(33-35) Due to the differences in the coefficient of thermal expansion among the metal bracket, adhesive material used and the tooth structure; repetitive contraction/expansion stresses are generated with thermal cycling and may result in bond failure.(31,36) Moreover, thermocycling may lead to increased water absorption or increased solubility of the adhesive material used(37) resulting in deteriorating bond strength. Christensen(38) explained the observed reduction in bond strength between in-vitro and in-vivo studies due to thermal changes happening in the mouth. ISO/TR 11405 recommended 500 cycles (39) for thermal cycling testing of dental material. However, Hasegawa et al (19, 32, 40) reported that 500 thermal cycles might not be enough to affect bond strength.

Adhesives and composites showed tendency to biodegrade as a result of exposure to fluids, causing bond strength deterioration over time. (41-43) In vitro immersion in water for 12 weeks resulted in a significant reduction in the bond strength of brackets with most of the deterioration in bond strength was observed at 4th week followed by a stable period of several weeks(44).

Therefore, a new adhesive should be subjected to 2 aging challenges; storage in water and thermal cycling.(26) Therefore, the current study involved a thermocycling challenge with a 2-fold increase in the ISO recommended thermal cycles subjecting the specimens to (1000) cycles,(41,42) and the water immersion challenge involving immersing the specimens in water for 6 weeks.(12,41)

The results of the current study showed that the bond strength of the control group was not affected by thermocycling and aging; however, the SBS was reduced significantly in all the other study groups. However, SBS remained within the recommended clinical range in the HS group and VF+P group, it decreased significantly below the recommended range in the VF group. These results show that phosphoric acid etching did not enhance the bond strength of the brackets bonded with Vertise flow at 15 minutes or 24 hours debond, however, it limited the bond strength deterioration when the specimens were subjected to aging and thermocycling.

Before explaining the effects of both aging and thermocycling on SBS in the different groups, we need to take a look at ARI pattern that was observed in the current study. At 15min debond, all groups showed a similar distribution between scores 2 and 3, meaning that the failure was cohesive in nature and the resin enamel interface was relatively sound and good. However, after thermocycling and aging, there was a significant reduction in the specimens showing score 2 in all the groups, except the control (TXT) group as ARI scores for brackets bonded using TXT did not significantly changed. Thermocycling and aging resulted in the appearance of more score 4 in groups HS, VF and VF+P; and exceptional appearance of score 5 in the VF group. The recording of scores 4 and 5 means that the resin-enamel adhesion is starting to deteriorate leaving lesser amount or no composite on the enamel surface. These observations suggest that thermocycling and aging had significant effect on bonding at adhesive-enamel interfaces with two key factors that influenced it; type of the adhesive used and the phosphoric acid pretreatment of enamel.

In the light of these 2 observations; the significant reduction in the SBS and the quality at adhesive-enamel interface after thermocycling and aging, some explanation could be suggested.

Heliosit is a resin that requires no additional primer, and this would affect its penetration capability making it more limited (45) probably as a result of the abundant bisphenol-A glycol dimethacrylate (Bis-GMA).(46) Moreover, Heliosit gave the impression of being an unfilled adhesive under scanning electron microscope (SEM) and transmission electron microscope (TEM), and it showed the significantly lowest Vickers hardness score.(47) The lesser filler content of Heliosit Orthodontic may be intended to reduce its viscosity and hence increase its penetration into enamel resin tags as no bonding agent is used with it. Faltermeier et al. (32) found that higher filled adhesives provide greater bond strength than lower filled or unfilled resins. The reduced viscosity of Heliosit was very apparent in the manipulation of the brackets during the bonding procedures where excessive bracket movement on tooth surface was noticed prior to resin curing.

Moreover, as the filler content decreases, polymerization shrinkage increases resulting in microgaps between the adhesive and the tooth surface.(48) Therefore, the low filler content of Heliosit; as fillers are added to improve mechanical properties of the resins such as increased strengthen and stiffness, reduce dimensional changes, and improve handling(49-51); altogether with the absence of bonding application before resin bonding could explain the significant deterioration in the resin physical and mechanical properties and the deterioration in adhesive-enamel interface with thermocycling and aging.

According to the Vertise Flow Technical Bulletin, Vertise flow is a self-adhering composite, containing glycerol phosphate dimethacrylate (GPDM). GPDM is a functional monomer that is responsible for adhesion to the tooth structure. The results of the current study showed that when vertise flow composite was used without phosphoric acid enamel etching; SBS deteriorated significantly after aging and thermocycling, presenting the weakest link in the interface between enamel and the adhesive. On the other hand, phosphoric acid etching significantly enhanced the bonding strengths. It was found that pretreatment of the enamel surface prior to the use of either self-etch resins or self-etch bonding agents with phosphoric acid increases bond strength.(14,32)This might be explained due to the presence of soluble-resistant surface enamel layer and self-etch bonding agents are characterized by reduced ability to sufficiently etch and penetrate the enamel surface.(48) This in turn will result in poor resin penetration into the enamel. Phosphoric acid etching on the contrary will remove this outer layer and will subsequently result in more resin penetration and increased bond strength. Moreover, the chemical bond to calcium ions of the tooth material (provided by GPDM in vertise flow) does not seem to be very stable when subjected to aging and thermocycling.

As brackets are bonded temporarily to enamel surfaces, it is advantageous for both the orthodontist and the patient to have no adhesive remnant on the enamel surface at debond with all or most of the bonding adhesive remaining at bracket bases. This concept would result in easier and faster enamel cleaning procedures with less risk of enamel damage.

However, brackets should remain functioning with acceptable bond strength till the end of treatment. The results of the current study showed that both HS and VF+P groups had acceptable bond strength and at the same time less residual resin on the enamel surface after thermocycling and aging compared to the control group TXT. This makes Heliosit and Versatile flow with pre-etched enamel a suitable choice for use as a bracket adhesive in orthodontics.

Conclusions

1. At 15 minutes debond testing; Vertise flow (either with or without enamel pre-etching) and Transbond had clinically acceptable bond strength. However Heliosit recorded the least SBS and less than the clinically accepted value.
2. Thermocycling and aging resulted in significant reduction in bond strength in all the study groups except in control group (TXT). However, the SBS

remained within the acceptable clinical value in groups HS and VF+P.

3. The use of Vertise Flow without enamel pre-etch resulted in SBS below the clinically acceptable value after thermocycling and aging.

4. Both Vertise Flow (when used with pre-etched enamel) and Heliosit can be used in orthodontic practice, offering simplified bonding procedures associated with clinically acceptable bond strenght and minimal amount of remaining adhesive on enamel surface at debond.

Study limitations:

Bonding resins are subjected to too many challenges in the most complicated environment of the oral cavity. This invitro study tried to mimic the complicated oral environment as much as possible; by subjecting the specimens to thermocycling and aging challenges. However, other factors such as forces (vertical and lateral) transmitted to the bracket-resin and/or tooth-resin should be put into consideration when evaluating the results of the current study. To achieve most realistic and accurate results, an in vivo study is recommended.

References

1. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. Dent Res. 1955; 34:849-53.

2. Newman GV. Epoxy adhesives for orthodontic attachments: Progress report. Am J Orthod 1965;51:901‑12.

3. De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, Van Meerbeek A. A critical review of the durability of adhesion to tooth tissue: methods and results. J Dent Res 2005; 84: 118-132.

4. Reynolds IR. A review of direct orthodontic bonding. Br J Orthod 1975;2:171‑8.

5. Ritter DE, Ritter AV, Bruggeman G, Locks A, Tulloch JF. Bond strengths and adhesive remnant index of self-etching adhesives used to bond brackets to instrumented and uninstrumented enamel. Am J Dent 2006;19:47-50.

6. Park SB, Son WS, Ko CC, Garcia-Godoy F, Park MG, Kim HI, Kwon YH. Influence of flowable resins on the shear bond strength of orthodontic brackets. Dent Mater J 2009; 28: 730- 734.

7. Ryou DB, Park HS, Kim KH, Kwon TY. Use of flowable composites for orthodontic bracket bonding. Angle Orthod 2008; 78: 1105-1109.

8. Ivoclar Vivadent. Heliosit Orthodontic product profile. Liechtenstein: Ivoclar Vivadent; 2003.

9. Krishnan S, PandianS, Rajagopal R. Six-month bracket failure rate with a flowable composite: A split-mouth randomized controlled trial. Dent. Press J Orthod. 2017;22(2):69-76.

10 . Durrani OK. In vitro comparison of shear bond strength of Transbond XT and Heliosit Orthodontic as Direct bracket bonding adhesives. Pakistan Oral Dent J. 2008;28(2):203-6.

11. Bradburn G, Pender N. An in vitro study of the bond strength of two light cured composites used in the direct bonding of orthodontic brackets to molars. Am J Orthod Dentofacial Orthop. 1992;102(5):418-26.

12. Murray SD, Hobson RS. Comparison of in vivo and in vitro shear

bond strength. Am J Orthod Dentofac Orthop. 2003;123(1):2-9.
13. Goracci C1, Margvelashvili M, Giovannetti A, Vichi A, Ferrari M. Shear bond strength of orthodontic brackets bonded with a new self-adhering flowable resin composite. Clin Oral Investig. 2013;17(2):609-17.
14. Barbosa IV, Ladewig VM, Almeida-Pedrin RR, Cardoso MA, Santiago Junior JF, Conti ACCF. The association between patient's compliance and age with the bonding failure of orthodontic brackets: a cross-sectional study. Prog Orthod. 2018;19:11.
15. Elekdag-Turk S, Turk T, Isci D, Ozkalayci N. Thermocycling effects on shear bond strength of a self-etching primer. Angle Orthod. 2008;78:351-6.
16. Zachrisson YO, Zachrisson BU, Büyükyilmaz T. Surface preparation for orthodontic bonding to porcelain. Am J Orthod Dentofacial Orthop. 1996;109:420–30.
17. Demirtas HK, Akin M, Ileri Z, Basciftci FA. Shear-bond-strength of orthodontic brackets to aged nano-hybrid composite-resin surfaces using different surface preparation. Dent Mater J. 2015;34:86–90.
18. Morresi AL, D'Amario M, Capogreco M, Gatto R, Marzo G, D'Arcangelo C ,et al. Thermal cycling for restorative materials: does a standardized protocol exist in laboratory testing? A literature review. J Mech Behav Biomed Mater. 2014;29:295-308.
19. Bishara S E, Ostby A W, laffoon J F, Warren J 2007 Shear bond strength comparison of two adhesive systems following thermocycling. Angle Orthodontist 77: 337–341
20. Nasiri M, Mirhashemi SAH, Ardavan Etemadi A, et al. Evaluation of the Shear Bond Strength and Adhesive Remnant Index in Debonding of Stainless Steel Brackets Assisted with Nd:YAG Laser Irradiation. Front Dent. 2019; 16(1):38-46.
21. Carvalho RM, Santiago SL, Fernandes CA, Suh BI, Pashley DH. Effects of prism orientation on tensile strength of enamel. J Adhes Dent. 2000 ;2(4):251–7.
22. Millett DT, Gordon PH. A 5-year clinical review of bond failure with a no-mix adhesive (Right on). Eur J Orthod . 1994;16(3):203–11.
23. Vinagre AR, Messias AL, Gomes MA, Costa AL, Ramos JC. Effect of time on shear bond strength of four orthodontic adhesive systems. Rev Port Estomatol Med Dent e Cir Maxilofac. 2014;55(3):142–51.
24. Rock WP, Abdullah MS. Shear bond strengths produced by composite and compomer light cured orthodontic adhesives. J Dent;25:243–9.
25. Klocke A, Shi J, Vaziri F, Kahl-Nieke B, Bismayer U. Effect of time on bond strength in indirect bonding. Angle Orthod. 2004;74(2):245–50.
26. Bishara SE, Laffoon JF, VonWald L, Warren J. Effect of time on the shear bond strength of cyanoacrylate and composite orthodontic adhesives. Am J Orthod Dentofac Orthop. 2002;121(3):297–300.
27. Wendl B, Droschl H. A comparative in vitro study of the strength of directly bonded brackets using different curing techniques. Eur J Orthod . 2004;26(5):535–44.

28. Turk T, Elekdag-Turk S, Isci D. Effects of self-etching primer on shear bond strength of orthodontic brackets at different debond times. Angle Orthod. 2007;77(1):108–12.
29. Chamda RA, Stein E. Time-related bond strengths of light-cured and chemically cured bonding systems: an in vitro study. Am J Orthod Dentofacial Orthop. 1996;110(4):378–82.
30. Greenlaw R, Way DC, Galil KA. An in vitro evaluation of a visible light-cured resin as an alternative to conventional resin bonding systems. Am J Orthod Dentofac Orthop. 1989;96(3):214–20.
31. Helvatjoglu-Antoniades M, Koliniotou-Kubia E, Dionyssopoulos P. The effect of thermal cycling on the bovine dentine shear bond strength of current adhesive systems. J Oral Rehabil 2004;31(9):911–7.
32. Faltermeier A, Behr M, Müssig D 2007 A comparative evaluation of bracket bonding with 1-, 2-, and 3-component adhesive systems. Am J Orthod Dentofac Orthop 132;144.e1-5.
33. øilo G, Austrheim EK. In vitro quality testing of dentin adhesives. Acta Odontol Scand. 1993;51(4):263–9.
34. Price RB, Dérand T, Andreou P, Murphy D. The effect of two configuration factors, time, and thermal cycling on resin to dentin bond strengths. Biomaterials. 2003;24(6):1013–21.
35. Abe Y, Lambrechts P, Inoue S, Braem MJA, Takeuchi M, Vanherle G, et al. Dynamic elastic modulus of “packable” composites. Dent Mater. 2001;17(6):520–5.
36. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent. 1999;27(2):89–99.
37. Daub J, Berzins DW, Linn BJ, Bradley TG. Bond strength of direct and indirect bonded brackets after thermocycling. Angle Orthod. 2006;76(2):295–300.
38. Christensen GJ. Has tooth structure been replaced? J Am Dent Assoc 2002;133(1):103–5.
39. ISO - ISO/TR 11405:1994 - Dental materials — Guidance on testing of adhesion to tooth structure. Available from: https://www.iso.org/standard/19347.html
40. Hasegawa T, Retief DH, Russell CM, Denys FR. Shear bond strength and quantitative microleakage of a multipurpose dental adhesive system resin bonded to dentin. J Prosthet Dent. 1995 May ;73(5):432–8.
41. Gwinnett AJ, Yu S. Effect of long-term water storage on dentin bonding. Am J Dent. 1995 Apr;8(2):109–11.
42. Kato G, Nakabayashi N. The durability of adhesion to phosphoric acid etched, wet dentin substrates. Dent Mater . 1998;14(5):347–52.
43. Kitasako Y, Burrow MF, Nikaido T, Tagami J. The influence of storage solution on dentin bond durability of resin cement. Dent Mater. 2000;16(1):1–6.
44. Abdel-Haffiez SH, Zaher AR, Elharouny NM. Effects of a filled fluoride-releasing enamel sealant versus fluoride varnish on the prevention of enamel demineralization under

simulated oral conditions. J World Fed Orthod. 2013;2(3).
45. Knox J, Jones ML, Hubsch P, Middleton J. The influence of orthodontic adhesive properties on the quality of orthodontic attachment. Angle Orthod . 2000;70(3):241–6.
46. Paris S, Meyer-Lueckel H, Cölfen H, Kielbassa AM. Penetration coefficients of commercially available and experimental composites intended to infiltrate enamel carious lesions. Dent Mater 2007;23(6):742–8.
47. Vilchis RJS, Hotta Y, Yamamoto K. Examination of six orthodontic adhesives with electron microscopy, hardness tester and energy dispersive X-ray microanalyzer. Angle Orthod 2008;78(4):655–61.
48. Arhun N, Arman A, Çehreli SB, Arikan S, Karabulut E, Gülşahi K. Microleakage beneath ceramic and metal brackets bonded with a conventional and an antibacterial adhesive system. Angle Orthod 2006;76(6):1028–34.
49. Almaz M, Oba A, Sönmez I, Sönmez D. Comparison of shear bond strength of self-adhering flowable composite with different flowable composites to dentin. Eur J Gen Dent . 2016;1;5-10.
50. Scougall-Vilchis RJ, Ohashi S, Yamamoto K. Effects of 6 self-etching primers on shear bond strength of orthodontic brackets. Am J Orthod Dentofac Orthop. 2009;135(4):424–5.
51. Scougall Vilchis RJ, Yamamoto S, Kitai N, Yamamoto K. Shear bond strength of orthodontic brackets bonded with different self-etching adhesives. Am J Orthod Dentofac Orthop 2009;136(3):425–30.