Clin Oral Invest (2013) 17:609–617
DOI 10.1007/s00784-012-0729-x

ORIGINAL ARTICLE

Shear bond strength of orthodontic brackets bonded with a new self-adhering flowable resin composite

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Received: 14 June 2011 / Accepted: 9 April 2012 / Published online: 27 April 2012

Abstract
Objectives This study aims to assess the shear bond strength (SBS) to enamel and the distribution of failure modes of brackets bonded using a new self-adhering flowable resin composite (Vertise Flow, VF), with or without preliminary phosphoric acid etching (PAE).
Materials and methods Eighty extracted premolars were randomly divided into four groups (n=20): (1) etch-and-rinse adhesive (E&R), PAE/Transbond XT Primer/Transbond XT Paste (3M Unitek); (2) self-etch adhesive (SE), Transbond Plus Self–Etching Primer (3M Unitek)/Transbond XT Paste; (3) VF; (4) PAE/VF. In each group, 10 bracketed teeth were debonded within 30 min, while the remaining teeth were subjected to thermocycling before testing. SBS and adhesive remnant index were recorded.
Results SE measured significantly lower early SBS than PAE/VF. Early SBSs recorded by VF were slightly higher yet statistically similar to those of E&R. Such levels of adhesion were achieved by VF regardless of preliminary PAE. After thermocycling, VF measured the lowest SBS. When debonded early, VF and SE tended to leave less residues on enamel surface than E&R. After thermocycling, the failure pattern changed significantly for VF and PAE/VF specimens that all exhibited adhesive failures at the tooth–bracket interface.
Conclusions VF achieved early bracket SBSs similar to E&R. Following thermocycling, VF and PAE/VF manifested a significant decrease in SBS.
Clinical relevance Although the simplified handling and the satisfactory early SBS of VF may prompt its use for bracket bonding, the decrease in retention noted after thermocycling warns that the issue of bond durability should be thoroughly addressed prior to endorsing this clinical application of VF.

Keywords Self-adhering flowable composite · Self-etch adhesive · Etch-and-rinse adhesive · Orthodontic brackets · Bond strength · Adhesive remnant index (ARI)

Introduction

The traditional procedure for bonding orthodontic brackets to teeth requires phosphoric acid etching of the enamel surface and sealing with a layer of hydrophobic resin, preliminarily to bracket bonding with a resin composite paste. The “etch-and-rinse” approach has been successfully used for several years in orthodontic bracket bonding [1]. However, more recently self-etch adhesives have also been proposed for this purpose. Such systems rely on acidic resin monomers for simultaneous partial demineralization and infiltration of the substrate. The preponderance of in vitro [2–26] and in vivo [27–33] studies indicate that self-etch adhesives can effectively bond orthodontic brackets to enamel. Moreover, the gentler etch of self-etching primers has been reported to produce less enamel loss than phosphoric acid [9, 10, 34, 35] and to minimally affect the nanomechanical properties of enamel [36]. From a clinical standpoint, by avoiding etching and rinsing, self-etch adhesives allow to

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simplify the bonding procedure and reduce chair time. Such advantages are attractive to clinicians, particularly when patient compliance is an issue. The latest years have also seen the introduction of self-adhesive resin cements that do not require any pretreatment of the surface preliminarily to bonding. Such materials, originally proposed for luting indirect restorations, have also been tested with orthodontic brackets, as they have the potential to simplify brackets' bonding to a one-step procedure [1, 37–41]. However, in all these tests, the self-adhesive resin cements measured significantly lower shear bond strengths to enamel than the etch-and-rinse adhesive system that served as a control. Such statistically significant difference emerged when testing was performed 30 min [1] or 24 h [38, 39] after bonding, as well as after thermocycling [37, 40, 41]. It was also noticed that the self-adhesive resin cements tended to leave less adhesive on the tooth than the etch-and-rinse adhesive [1, 37–39].

Lately, a new self-adhering flowable resin composite, Vertise Flow (Kerr, Orange, CA, USA), has been launched into the dental market. Vertise Flow has been proposed as an adhesive-free restorative material indicated for the restoration of small class I cavities, class V cavities, and noncarious cervical lesions, as well as for lining in class I and class II restorations, pit and fissure sealing, and porcelain repairs (Vertise Flow Technical Bulletin). However, the simplified handling of Vertise Flow makes this material potentially useful also for bonding orthodontic brackets. Vertise Flow was recently tested in vitro for water sorption-related phenomena [42, 43]. In addition, laboratory and clinical studies are ongoing to assess the performance of Vertise Flow as a restorative material. Nevertheless, no evidence has so far been collected on the applicability of this material to orthodontic bracket bonding. Therefore, the present study was aimed at assessing shear bond strength to enamel and distribution of failure modes of stainless steel brackets bonded with the new self-adhering flowable resin composite. For comparative purposes, an etch-and-rinse adhesive and a self-etch adhesive used in combination with the proprietary resin composite were also tested. Moreover, as the manufacturer recommends that for enhanced adhesion of Vertise Flow to unground enamel, the substrate should preliminarily be etched with phosphoric acid; a further objective of this investigation was to assess whether this additional step contributed significantly to the bracket retentive ability of Vertise Flow. Additionally, the effect on bond strength and failure mode of thermocycling as a procedure to simulate aging was assessed. Therefore, the following null hypotheses were tested: (1) Early after bonding, as well as following thermocycling to simulate aging brackets bonded with the new self–adhesive flowable composite resist similar debonding forces and exhibit comparable failure patterns to those of brackets bonded with an etch–and–rinse or a self–etch adhesive systems that have been routinely used for orthodontic bracket bonding. (2) Preliminary phosphoric acid etching of enamel does not significantly change the shear bond strength of brackets bonded with Vertise Flow or their failure pattern.

Materials and methods

Eighty freshly extracted human premolars were collected. The criteria for selection were buccal surfaces free from caries, previous restorations, and visible cracks from the extraction forceps. Teeth were cleansed of tissue and debris and stored in 1 % chloramine-T until use in the experiment. Utilizing a plastic mold, each tooth was embedded in fast-setting acrylic resin (Paladur Heraeus Kulzer, Inc., South Bend, IN, USA), orienting the facial surface perpendicular to the bottom of the mold so that the bonded surface will be parallel to the force applied during the shear strength test. Care was taken to keep the teeth moist during acrylic resin polymerization. Teeth were then stored in water at 37°C until bonding of premolar stainless steel brackets (Mini Master Series, American Orthodontics, Sheboygan, NY, USA). The average bracket base surface area reported by the manufacturer was verified by measuring with a digital caliper (Mitutoyo, Miyazaki, Japan). The area of 10 brackets was recorded**.** The mean and the standard deviation values of the measured areas were calculated to be (mean ± standard deviation) 9.15 ± 0.02 mm^2. The bonding surface of each tooth was cleansed for 10 s with a mixture of water and fluoride-free pumice in a rubber polishing cup by using a low-speed handpiece. The enamel surface was rinsed with water to remove pumice and debris and then dried with an oil-free air stream.

Four groups of 20 teeth were randomly formed, based on the procedure followed for bracket bonding:

Group 1 Brackets were bonded with Transbond XT Primer and Transbond XT Paste, following enamel etching with 37 % phosphoric acid etchant gel (3M Unitek, Monrovia, CA, USA). The etching gel was applied to the bonding surface for 15 s according to the manufacturer's instructions. The etched enamel was rinsed with abundant water spray for 5 s and dried with oil-free air spray. A layer of Transbond XT Primer was applied on the prepared enamel surface with a brush and air-thinned with a gentle air blow. A small amount of Transbond XT Paste was applied onto the bracket base, and the bracket was immediately placed on the center of the tooth facial surface and firmly seated using a scaler. Excess resin composite was removed from the bracket base periphery with the scaler and light-curing was performed with the quartz–tungsten–halogen light Optilux 501 (Kerr, Orange, CA, USA; output 850 mW/cm^2), positioning the tip for 10 s on the mesial and 10 s on the distal side of the bracket.

Group 2 Brackets were bonded with Transbond Plus Self–Etching Primer (3M Unitek, Monrovia, CA, USA) and Transbond XT Paste. The components of the primer were mixed in the reservoir, and the solution was rubbed on the tooth surface for 3–5 s and air-thinned with a gentle air blow. Then, Transbond XT Paste was applied onto the bracket base, and the bracket was bonded as described in group 1.

Group 3 Brackets were bonded with the self-adhering composite Vertise Flow (Kerr, Orange, CA, USA). A 0.5-mm thick layer of Vertise Flow was applied onto the enamel surface and rubbed for 15–20 s with the proprietary microbrush. Then, a small amount of resin composite was placed onto the bracket base, the bracket was seated using a scaler, excess resin composite was removed from the bracket base periphery with the scaler, and light-curing was performed as described in group 1.

Group 4 Brackets were bonded using Vertise Flow, following enamel etching with phosphoric acid. Etching was performed as described for group 1. Bracket bonding was carried out as reported for group 3. Table 1 illustrates the chemical composition of the tested materials.

All bracket placements were carried out by the same operator (C.G.). After bonding, for half of the teeth in each group (n=10), debonding forces were determined within 30 min from the time of bonding. This is the amount of time commonly elapsing before archwire ligation that imparts the first functional stress to the just established adhesive bond [1, 40, 44]. The other bracketed teeth (n= 10 per group) were stored for 24 h in deionized water at 37° C and thermocycled at 5 and 55°C for 1,000 cycles for artificial aging. A complete cycle lasted 65 s (dwell time, 30 s; transfer time, 5 s) [2]. For debonding, a steel rod with a flattened end was attached to the crosshead of a universal testing machine (Controls, Milano, Italy). Specimens were secured in the lower jaw of the machine so that the bonded bracket base was parallel to the shear force direction. Specimens were stressed in the occlusal–gingival direction at a crosshead speed of 1 mm per minute. The load necessary to debond the bracket was recorded in newtons, and the bond strength was expressed in megapascals by dividing the load at failure in newtons by the surface area of the bracket in square millimeter. After debonding, the bracket bases and the enamel surfaces were examined under an optical microscope at ×20 magnification. The modified adhesive remnant index (ARI) proposed by Ostby et al. [44] was used to assess the amount of adhesive left on the enamel surfaces. This index ranges from 0 to 5, and the scores are defined as follows: score 1, all of the adhesive remained on the tooth; score 2, more than 90 % of the adhesive on the tooth; score 3, 10–90 % of the adhesive on the tooth; score 4, less than 10 % of the adhesive on the tooth; and score 5, no adhesive remained on the tooth.

Statistical analysis

Shear bond strength

As group variances were not homogeneous according to the Levene test, the use of the two-way analysis of variance with bond strength as the dependent variable, bonding system and testing time as factors were precluded. Therefore, two separate one-way analyses of variance were performed on the bond strength data measured 30 min after bonding and on those recorded in thermocycled specimens, having preliminarily checked that in each data set, distribution was normal (Kolmogorov–Smirnov test) and group variances were homogeneous (Levene test). The Tukey test was then used for post hoc comparisons. In each group, the statistical significance of the difference in bond strength between specimens loaded within 30 min from the time of bonding and after thermocycling was assessed with the Student t test for independent samples for all the groups except group 4.

Table 1 Chemical composition of the tested materials

Material	Batch number	Chemical composition
Transbond XT Etchant Gel (3M Unitek, Monrovia, CA, USA)	9NK	Water, phosphoric acid, amorphous silica
Transbond XT Primer (3M Unitek, Monrovia, CA, USA)	N2U7652	Bisphenol A diglycidyl ether dimethacrylate, triethylene glycol dimethacrylate, 4-(dimethylamino)-benzeneethanol, *dl*-camphorquinone, hydroquinone
Transbond Plus Self–Etching Primer (3M Unitek, Monrovia, CA, USA)	458488	Methacrylate ester derivative, water, *dl*-camphorquinone, dipotassium hexafluorotitanate
Transbond XT Paste (3M Unitek, Monrovia, CA, USA)	N210949	Silane-treated quartz (70–80 % in weight), bisphenol A diglycidyl ether dimethacrylate, bisphenol A bis(2-hydroxyethyl ether) dimethacrylate, silane-treated silica, diphenyliodonium hexafluorophosphate
Vertise Flow (Kerr, Orange, CA, USA)	3341704	Glycerol phosphate dimethacrylate, prepolymerized filler, 1-μ barium glass filler, nano-sized colloidal silica, nano-sized ytterbium fluoride

In the latter group, the Mann–Whitney *U* test had to be used, as the data did not pass the test of homogeneous variances. In all the analyses, the level of significance was set at $p<0.05$.

ARI

Two separate Kruskall–Wallis nonparametric analyses of variance were applied to the data collected from teeth loaded within 30 min and from teeth tested after thermocycling. The Dunn's multiple range test was used for post hoc comparisons. In each group, the statistical significance of the difference in ARI between specimens loaded within 30 min and after thermocycling was assessed with the Mann–Whitney *U* test. In all the analyses, the level of significance was set at $p<0.05$. Statistical calculations were handled by the SPSS software (version 12.0, SPSS, Chicago, IL, USA).

Results

For the specimens tested within 30 min from the time of bonding, descriptive statistics of shear bond strengths and ARI scores are reported in Tables 2 and 3, respectively. The one-way ANOVA revealed the existence of statistically significant differences in shear bond strength among the groups ($p=0.022$). Specifically, the Tukey test demonstrated that the self-etching adhesive system (group 2) yielded significantly lower bond strengths than the new self-adhesive flowable composite used in combination with phosphoric acid (group 4). The bond strength values recorded by the adhesive-free flowable composite were slightly higher yet statistically similar to those of the etch-and-rinse adhesive system. Such levels of adhesion were achieved by Vertise Flow regardless of the preliminary phosphoric acid etching of the enamel substrate. Statistically significant differences emerged also in the ARI scores ($p=0.006$). Specimens treated with phosphoric acid etching (groups 1 and 4) tended to retain a greater amount of resin on the enamel surface after debonding. According to the post hoc test, the differences in ARI scores were statistically significant between the etch-and-rinse adhesive (group 1) and the "simplified" bonding procedures using either the self-etching primer (group 2) or the self-adhesive composite (group 3).

Tables 4 and 5 respectively report the descriptive statistics of bond strengths and ARI for specimens tested after thermocycling. Statistically significant differences in bond strength existed among all the groups ($p<0.001$). The highest bond strengths were recorded by the etch-and-rinse adhesive system (group 1), while the lowest values of adhesion were measured by Vertise Flow (group 3). Specimens treated with phosphoric acid preliminarily to the application of Vertise Flow (group 4) demonstrated a stronger bond than those bonded with the sole self-adhesive flowable composite (group 3), yet the adhesion of brackets bonded with Vertise Flow on etched enamel (group 4) was found to be significantly lower than that of brackets retained by Transbond XT Paste (groups 1 and 2). Groups differed significantly also with regard to the distribution of failure modes ($p<0.001$). Brackets bonded with Vertise Flow either including (group 4) or omitting (group 3) phosphoric acid etching left a greater amount of adhesive material on enamel after debonding than brackets bonded with Transbond XT Paste (groups 1 and 2).

When comparing the bond strengths recorded early and after artificial aging for each bonding system, it emerged that the adhesion of brackets bonded with Vertise Flow alone (group 3) or in combination with phosphoric acid (group 4) declined significantly following thermocycling (Table 6). Also, the distribution failure modes changed significantly with aging for all the tested bonding systems except the self-etching primer (Table 7).

Discussion

It is understandably desirable during orthodontic treatment to ease and fasten chair time procedures, as well as to increase patient comfort. The introduction of self-etch adhesives and the attempt to use self-adhesive resin cements for orthodontic bracket bonding have aimed at this objective. The recent introduction of an adhesive-free flowable resin composite might represent a further advancement in this trend. The present investigation intended to verify whether

Table 2 Descriptive statistics of shear bond strengths in megaPascals (MPa) of specimens tested within 30 min from the time of bonding

Groups	Number	Mean	SD	Significance $p<0.05$
1—Phosphoric acid/Transbond XT Primer/Transbond XT Paste	10	9.80	2.28	AB
2—Transbond Plus Self–Etching Primer/Transbond XT Paste	10	7.45	2.35	B
3—Vertise Flow	10	10.13	2.86	AB
4—Phosphoric acid/Vertise Flow	10	11.86	4.17	A

In the "Significance" column, different letters label statistically significant between-group differences

Table 3 Descriptive statistics of adhesive remnant index (ARI) scores of specimens tested within 30 min from the time of bonding

Groups	Number	Median	Interquartile range (25–75 %)	Significance $p<0.05$
1—Phosphoric acid/Transbond XT Primer/Transbond XT Paste	10	2.5	2–3	A
2—Transbond Plus Self–Etching Primer /Transbond XT Paste	10	4	3–4	B
3—Vertise Flow	10	3.5	3–4	B
4—Phosphoric acid/Vertise Flow	10	3	2–4	AB

In the "Significance" column, different letters label statistically significant between-group differences

the reduction in working steps enabled by the new self-adhering flowable composite had an influence on bracket retention and debonding pattern. Based on the results of the study, both formulated null hypotheses have to be rejected, as the experimental groups differed significantly with regard to the shear bond strength of the brackets and the distribution of failure modes. The new self-adhering flowable composite yielded early bracket retentive strengths similar to those of a conventional etch-and-rinse adhesive system that has been tested as a control material in several previous studies [1, 4–6, 9, 10, 14–16, 18, 19, 21, 24–30, 32, 33, 41]. The bonding mechanism of Vertise Flow relies on the adhesive monomer glycerol phosphate dimethacrylate (GPDM), whose phosphate group is responsible for acid etching and chemical bonding with calcium ions of the dental substrate. Mechanical strength is provided to the material by the cross-linking of methacrylate functional groups with other methacrylate monomers (Vertise Flow Technical Bulletin). In order to promote the interaction of the acidic monomers, the company recommends that the first, 0.5-mm thick layer of Vertise Flow should be brushed over the dental substrate for 15–20 s with the provided microbrush. In this regard, it should be noticed that brushing over the buccal enamel when bonding orthodontic brackets is easier than doing the same procedure within the boundaries of a class V or a small class I cavity in restorative dentistry. It should also be pointed out that for improved bonding to intact enamel, the company advises to preliminarily etch the substrate with phosphoric acid. In this investigation, phosphoric acid etching did not significantly add to the early bracket retentive potential of Vertise Flow, although it appeared to limit the drop in bond strength when the specimens were subjected to thermocycling. In comparison with Transbond Plus Self–Etching Primer, the other simplified adhesive system not requiring any etching step, Vertise Flow initially bonded more strongly. The pH declared by the manufacturer for Vertise Flow is 1.9, while a pH value of 1 has been reported for Transbond Plus Self–Etching Primer [44, 45]. Therefore, the results of the present investigation are in agreement with the findings of a previous study assessing the effect of self-etching primer's pH on the early shear bond strength of orthodontic brackets [44]. Having compared mild and aggressive self-etching primers, the authors concluded that the pH of the adhesive solution is not the main determinant of early shear bond strength. The latter is plausibly influenced to a relevant extent by other factors, such as the ability of the adhesive material to form a chemical bond to enamel and the material's intrinsic strength [44]. With reference to this study's results, it could be speculated that a greater capability of the GPDM monomer to develop a chemical bond with enamel in comparison with the methacrylate esters of Transbond Plus Self–Etching Primer might have accounted for the higher early shear bond strength measured by Vertise Flow. Another possible explanation for the higher bond strengths recorded by Vertise Flow in comparison with the self-etch adhesive system involves the polymerization kinetics and the dynamic of contraction stress development. When an adhesive is used in combination with a resin composite filled by 70–80 % in weight, such as Transbond XT Paste, the polymerization shrinkage stress of the latter is going to tax the bond just established on the dental substrate by the adhesive. As the bond strength to intact enamel of self-etch adhesives is known to be relatively low, the competition of the resin composite shrinkage stress can affect bracket retention to some extent. Conversely, the self-adhesive mechanism of Vertise Flow enables the material to undergo contraction stress

Table 4 Descriptive statistics of shear bond strengths in megapascals (MPa) of thermocycled specimens

Groups	Number	Mean	SD	Significance $p<0.05$
1—Phosphoric acid/Transbond XT Primer/Transbond XT Paste	10	11.70	2.44	A
2—Transbond Plus Self–Etching Primer/Transbond XT Paste	10	8.98	2.03	B
3—Vertise Flow	10	2.99	1.20	D
4—Phosphoric acid/Vertise Flow	10	6.56	1.05	C

In the "Significance" column, different letters label statistically significant between-group differences

Table 5 Descriptive statistics of adhesive remnant index (ARI) scores of thermocycled specimens

Groups	Number	Median	Interquartile range (25–75 %)	Significance $p<0.05$
1—Phosphoric acid/Transbond XT Primer/Transbond XT Paste	10	3	3–4	A
2—Transbond Plus Self–Etching Primer /Transbond XT Paste	10	4.5	3–5	A
3—Vertise Flow	10	1	1	B
4—Phosphoric acid/Vertise Flow	10	1	1	B

In the "Significance" column, different letters label statistically significant between-group differences

as it bonds to the substrate. Moreover, owing to the low elastic modulus, the flowable composite is expected to transmit less contraction stress to the interfaces while curing. Notwithstanding the satisfactory early outcome, in the present investigation, the bond strength of Vertise Flow manifested a remarkable decline with aging. Therefore, the stability of the bracket retentive potential of Vertise Flow emerges as an issue that requires further attention. Particularly, it seems pertinent to verify whether the hygroscopic expansion and solubility phenomena described for Vertise Flow as a result of increased water sorption [42, 43] may have an influence on its bracket retentive strength in time.

With regard to the etch-and-rinse and the self-etch adhesive, the finding of a similarity in bracket shear bond strengths before and after thermocycling is in line with the outcome of earlier studies [5, 52]. Also, the retention of a lower amount of Transbond XT adhesive on teeth debonded after thermocycling in comparison with early debonded specimens has been previously reported [5].

Beside bond durability, the rheologic properties of Vertise Flow should also be modified to target orthodontic bracket bonding. In its current formulation, the material is more fluid than the resin composites commonly used for orthodontic bracket bonding, such as Transbond XT Paste. Consequently, a greater tendency for bracket sliding was noticed when using Vertise Flow as compared with Transbond XT Paste. Moreover, when using Vertise Flow, the excess material tended to spread more easily around the bracket borders following bracket seating, and greater care was needed in the flash cleanup step. As a matter of fact, downward flow of material due to gravity has been previously described as a drawback of using flowable composites for bracket bonding [45]. It would therefore be desirable if the manufacturer could modify the viscosity of Vertise Flow to provide it in a less runny formulation. The latter should still be "brushable" on the substrate and adequate to ensure a close proximity between adhesive monomers and enamel, as the necessary condition for the development of the chemical bond on which the adhesion mechanism of Vertise Flow partly relies. Additionally, for the purpose of easier flash cleanup, the manufacturer may consider providing Vertise Flow in a color-changing formulation, allowing for the material to be colored on application and shifting to tooth color with curing. Such property is already featured by some presently marketed resin composites for orthodontic bracket bonding.

It is worth mentioning that the retentive strengths measured by brackets bonded with Vertise Flow after thermocycling were below the threshold of clinical acceptability (6–8 MPa) indicated in the classical review article by Reynolds [46, 47]. However, the use of such reference value was questioned in a recent systematic review and meta-analysis on in vitro orthodontic bond strength testing [48], based on the consideration that it has never actually been tested whether 6 to 8 MPa is sufficient in vitro bond strength for clinical use [49, 50]. In this regard, Eliades et al. [51] warned that the extrapolation of absolute values of bond strength and their comparison with a supposedly "clinically acceptable" threshold value should be avoided. As a matter

Table 6 Descriptive statistics of shear bond strengths in megapascals (MPa) of specimens tested 30 min within the time of bonding and of thermocycled specimens

Bonding system	Number	30 min after bonding		After thermocycling		Significance $p<0.05$
		Mean	SD	Mean	SD	
1—Phosphoric acid/Transbond XT Primer/Transbond XT Paste	10	9.80	2.28	11.70	2.44	$p=0.089$ NS
2—Transbond Plus Self–Etching Primer/Transbond XT Paste	10	7.45	2.35	8.98	2.03	$p=0.137$ NS
3—Vertise Flow	10	10.13	2.86	2.99	1.20	$p<0.001$*
4—Phosphoric acid/Vertise Flow	10	11.86	4.17	6.56	1.05	$p=0.001$*

NS The difference was not significant from a statistical standpoint

*The difference is statistically significant between the bond strengths recorded at the two testing times

Table 7 Descriptive statistics of adhesive remnant index (ARI) scores of specimens tested 30 min within the time of bonding and of thermocycled specimens

Bonding system	Number	30 min after bonding		After thermocycling		Significance $p<0.05$
		Median	Interquartile range (25–75 %)	Median	Interquartile range (25–75 %)	
1—Phosphoric acid/Transbond XT Primer/Transbond XT Paste	10	2.5	2–3	3	3–4	p=0.004*
2—Transbond Plus Self-Etching Primer/Transbond XT Paste	10	4	3–4	4.5	3–5	p=0.116 NS
3—Vertise Flow	10	3.5	3–4	1	1	p<0.001*
4—Phosphoric acid/Vertise Flow	10	3	2–4	1	1	p=0.002*

NS The difference is statistically significant between the scores recorded at the two testing times, while *The difference was not significant from a statistical standpoint

of fact, the bond strength data recorded in a study are related to experimental conditions that are specific to that trial and never completely apply to another testing environment. Conversely, it is advised that the interpretation of bond strength data should be limited to the relative effectiveness of the adhesive materials tested in the specific study [48, 51]. From this perspective, the finding of the present investigation that the new self-adhesive resin composite measured the lowest bond strength after thermocycling is noteworthy.

Microscopic observations of the failure sites added some useful information about the bond established by the tested materials. When considering early debonded specimens, in agreement with the findings of previous studies [9, 10, 12, 13, 16, 18, 19, 35, 38, 44, 52], when the etch-and rinse adhesive was used, more residual resin composite remained on the enamel surface. Recovering a sound, unblemished enamel surface after debonding should be the objective of the clinician. Several studies have highlighted that in comparison with etch-and-rinse systems, self-etch adhesives produce a milder etching effect and a lower depth of resin penetration into the enamel substrate, thus reducing the risk of enamel damage with debonding [6, 9, 34, 35, 44]. Iijima et al. reported that self-etch systems had a minimal effect on the nanomechanical properties of enamel, as a result of a chemical attack more limited than that of phosphoric acid [36]. On early debonded specimens, the new self-adhesive flowable composite Vertise Flow demonstrated a failure pattern comparable to that of the self-etch adhesive Transbond Plus Self–Etching Primer, with a prevalence of failures at the enamel–adhesive interface. Therefore, a similarly conservative interaction with enamel can be expected to occur when using Vertise Flow for bracket bonding. The finding that brackets bonded with Vertise Flow, when loaded within 30 min, tended to fail at the enamel site also implies that the early bond at the bracket–resin interface was most often stronger than the adhesion at the tooth–resin interface. It has been reported by the manufacturer of Vertise Flow that the material bonds well to nonprecious and precious alloys (Vertise Flow Technical Bulletin). However, after aging, all of the specimens bonded with Vertise Flow (groups 3 and 4) failed adhesively at the bracket–resin interface (Table 5). It can be derived from this finding that the exposure to water and temperature changes involved in thermocycling mainly affected the bond of the self-adhesive resin composite to the metal bracket base. Also, this observation appears worth of further investigation.

It has been stated that Vertise Flow can effectively bond to porcelain without the need for hydrofluoric acid etching and silane application (Vertise Flow Technical Bulletin). In order to verify these manufacturer's claims, it would be interesting to evaluate in future studies the adhesion to gold and porcelain restorations of brackets bonded with Vertise Flow. Likewise, it seems worth assessing the retentive strength to enamel of porcelain brackets bonded with the new self-adhering flowable composite.

Conclusions

Based on the outcome of the present in vitro study, the following conclusions can be drawn:

1. A new self-adhesive flowable resin composite originally designed for operative bonding procedures, when used to bond stainless steel brackets to enamel, achieved early bond strengths similar to those of a conventional etch-and-rinse adhesive system.
2. Similar to the failure mode distribution of a marketed self-etching adhesive system, the new self-adhering flowable composite tended to leave less residues on the enamel surface than the etch-and-rinse adhesive after early debonding. Such finding suggests that the etching effect of the adhesive-free composite was relatively mild, with reduced risk of enamel damage.
3. The new self-adhesive resin composite underwent a significant drop in its bracket retentive ability following

thermocycling. Aging weakened the adhesion at the interface with the bracket base, as all the failures occurred between resin and bracket in thermocycled specimens. The stability of the bond established by Vertise Flow to enamel and to different materials for orthodontic brackets manufacturing should be further investigated.

4. For improved handling of the adhesive-free flowable composite as a bracket-bonding material, its rheologic properties should preferably be changed to provide a more viscous paste, thus minimizing bracket shifting, reducing excess spread, and easing flash cleanup.
5. Although the simplified handling and the satisfactory early bracket retentive strength demonstrated by Vertise Flow may prompt its use for orthodontic bracket bonding, the decrease in retention noted in this study after thermocycling warns that the issue of bond durability should be thoroughly addressed prior to endorsing this clinical application of the new self-adhering flowable composite.

Conflict of interest The authors declare that they have no conflict of interest.

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