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Evaluation of Self-Adhering Flowable Composites on Repeated Bracket Bonding Process: An In Vitro Study

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ABSTRACT

Duration of orthodontic treatment becomes major concern. The present study compared shear bond strength (SBS) and adhesive remnant index (ARI) values of different adhesive systems with different application methods on rebonding process of retrieved orthodontic brackets. Eighty premolar teeth were equally divided into five groups. Transbond XT (TXT) which belongs to total-etch system was used in Group 1 as the control group. Nova Compo-SF (NC) and Vertise Flow (VF) (Kerr Dental, Italy) which are self-adhering flowable composites were used in Group 2 (NC+etch) and Group 3 (VF+etch) respectively with additional etching before application. Group 4 (NC) and Group 5 (VF) were used by following instructions of each brand. The brackets were debonded with a bracket removing plier and rebonded with the same procedures after sandblasting of the bracket and surface cleaning of the enamel. SBS and ARI were measured for each sample. Comparison between all groups was performed by Kruskal-Wallis test and chi-square test. The highest SBS was observed in NC+etch (median = 11.44, mean = 13.49±9.42), followed by NC (median = 10.17, mean = 11.35±6.55), TXT (median = 6.36, mean = 8.06±6.33), VF+etch (median = 5.68, mean = 6.75±4.58), and VF (median = 2.62, mean = 2.92±2.57), respectively. ARI 1 was observed in 81.3% of TXT whereas 62.5% of NC+etch. ARI 1, 2, and 3 were equally distributed in VF+etch group (31.3%). ARI 5 was observed in 37.5% of NC and 62.5% of VF. Analyses referred to statistically significant differences between five groups regarding both SBS and ARI ($p < 0.001$). As NC showed the highest SBS on rebonding process, it can be a promising alternative to TXT which is the gold standard.

Keywords: *Flowable composite; orthodontic brackets; rebonding; self-adhering; shear bond strength*

INTRODUCTION

Duration of orthodontic treatment has been a major concern for orthodontists and patients. Bracket failure during treatment will not only increase the chair time but also increase the total treatment duration (Stasinopoulos *et al.*, 2018). However, bracket failure is sometimes inevitable due to the patient-based, material-based, or practitioner-based reasons. In cases with severe rotations, debonding of the

brackets is necessary to have a better bracket repositioning (Salama *et al.*, 2018).

Rebonding is repeating the bracket bonding application of failed or debonded bracket again after surface cleaning of the enamel. Rebonding with the same bracket can be performed after removing the adhesive from both enamel surface and bracket base. Although there are various methods to clean bracket base (Al Maaitah *et al.*, 2013; Maringka *et al.*, 2017), sandblasting is an advantageous technique with its practical use in daily practice (Aksu & Kocadereli, 2013; Bahnasi *et al.*, 2013a; 2013b).

Various adhesive systems have been used in bracket bonding or rebonding procedures (Ewoldsen & Demke, 2001; Alkadhimi & Motamedi, 2019). Although improvements in these systems were done with the aim of lessening chair time, bond strength is the main factor that affects the success of bracket bonding. Many studies had investigated the bond strength of various adhesive systems in initial bracket bonding (Reicheneder *et al.*, 2009; Sharma *et al.*, 2014; Hellak *et al.*, 2016; Vaheed *et al.*, 2018; Griffin *et al.*, 2021). However, more studies are needed to compare the different adhesive systems including self-adhering flowable composites with respect to their shear bond strength (SBS) and adhesive remnant index (ARI). Nova Compo-SF (NC) (Imicryl, Turkey) is a novel self-adhering flowable composite that includes 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) and 4-methacryloxyethyl trimellitate anhydride (4-META) as the functional monomers. VF is another self-adhering flowable composite that includes a functional monomer called glycerol phosphate dimethacrylate (GPDMA). The objective of the present study was to compare the SBS and ARI values of brackets rebonded with conventional bracket bonding systems and different self-adhering flowable composite materials.

MATERIALS AND METHODS

The ethical approval for this in vitro study was obtained from Ethics Committee of Karatay University Faculty of Medicine, Turkey (Ref. no.: 2020/19). The flowchart of this study is given in Fig. 1. Eighty human premolar teeth that were freshly extracted for orthodontic and periodontal reasons were used in this in vitro study. After a detailed examination on stereomicroscope (Olympus SZ61, Olympus Optical Co. Ltd, Tokyo, Japan), only the teeth without caries, restoration, and enamel fracture were included in the study sample. Extracted teeth were stored in 0.1% thymol solution for 24 hours at 5°C to prevent bacterial contamination. The samples were transferred to distilled water and they were kept in distilled water at 37°C until the beginning of bracket bonding procedure. The distilled water was changed weekly. Before bracket bonding, the teeth were embedded vertically in self-curing acrylic resin (Imicryl, Konya, Turkey) in identical plastic cylinders from their apex to cementoenamel junction and waited until the polymerisation finish.

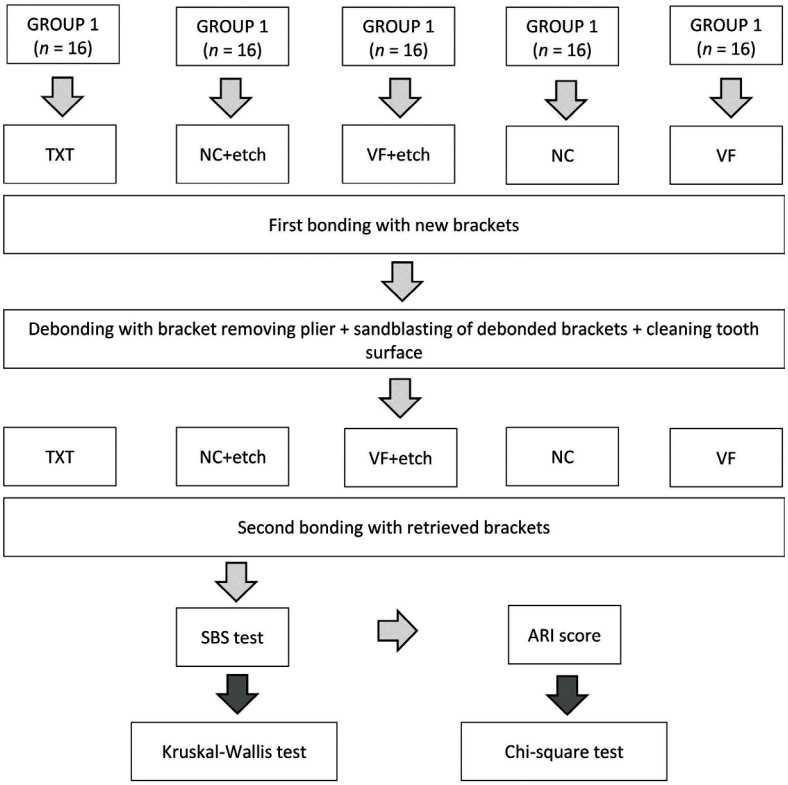

Fig. 1 Flowchart of the study.

Power calculation was performed by using an F-test, fixed effects, one-way analysis (G*Power 3.1 software; Heinrich Heine University, Dusseldorf, Germany). Required sample size for five groups was 80 for 0.9 power and 0.46 effect size (İşman *et al.*, 2012). Eighty premolar teeth were equally divided into five groups. Transbond XT (TXT) (3M Unitek, USA) which belongs to total-etch system was used in Group 1 as the control group. Nova Compo-SF (NC) (Imicryl, Turkey) and VF which are self-adhering flowable composites were used in Group 2 (NC+etch) and Group 3 (VF+etch) respectively with additional etching before application. Group 4 (NC) and Group 5 (VF) were used by following instructions of each brand. Before the initial bracket bonding and bracket rebonding processes, each tooth was polished with flour-free pumice for 10 seconds through a rubber cup. Premolar brackets (Jiscop Co., Ltd., Gunpo-si, South Korea) were used in each specimen. All procedures were performed by a single investigator in a consistent manner. Initial bonding procedure for each group was explained in Table 1. The brackets were debonded after initial bonding. Debonding was performed by one investigator through bracket removing plier with a force applied in cervicoocclusal direction. Enamel surface was cleaned with a tungsten carbide burr and polished with a flour-free pumice for 10 seconds. The bracket base was cleaned through sandblasting with 50 µm aluminium oxide particles under air pressure. For rebonding process, the same brackets were used on the same teeth with the same procedure as described in Table 1. Thermocycling was performed between 5°C and 55°C to all specimens with a dwell time of 30 seconds and a transfer time of 15 seconds for 5,000 cycles (Thermocycler THE 1100, SD Mechatronik GMBH, Feldkirchen Westerham, Germany).

Table 1 Bracket bonding application procedure for groups

Group	Material	Application
Group 1	TXT	Surface cleaning with pumice, rinse with water, air dry, etching with 37% phosphoric acid gel for 20 seconds, rinse with water, air dry, a thin layer of primer application, application of adhesive paste and bracket placement, a total of 40 seconds light curing (10 seconds per side).
Group 2	NC+etch	Surface cleaning with pumice, rinse with water, air dry, etching with 37% phosphoric acid gel for 20 seconds, rinse with water, air dry, application of NC-SF less than 0.5 mm layer on enamel surface, application of NC-SF to bracket base and bracket placement, waiting for 15 seconds before light curing, a total of 40 seconds light curing (10 seconds per side).
Group 3	VF+etch	Surface cleaning with pumice, rinse with water, air dry, etching with 37% phosphoric acid gel for 20 seconds, rinse with water, air dry, application and rubbing of VF less than 0.5 mm layer on enamel surface, application of VF to bracket base and bracket placement, a total of 40 seconds light curing (10 seconds per side).
Group 4	NC	Surface cleaning with pumice, rinse with water, air dry, application of NC-SF less than 0.5 mm layer on enamel surface, application of NC-SF to bracket base and bracket placement, waiting for 15 seconds before light curing a total of 40 seconds light curing (10 seconds per side).
Group 5	VF	Surface cleaning with pumice, rinse with water, air dry, application and rubbing of VF less than 0.5 mm layer on enamel surface, application of VF to bracket base and bracket placement, a total of 40 seconds light curing (10 seconds per side).

Notes: TXT = Transbond XT, NC+etch = Nova Compo-SF with etching, VF+etch = Vertise Flow with etching, NC = Nova Compo-SF, VF = Vertise Flow

SBS was measured with a universal testing machine (Devotrans Quality Control Test Equipment, Istanbul, Turkey) through a flat-end stainless steel rod at a speed of 1 mm/min (Fig. 2). The maximum force value in Newton was recorded at the time of bracket debonding. Then, SBS was calculated by dividing this value to bracket surface area and expressed in Megapascal (MPa).

After shear bond testing, the enamel surface was investigated under a stereomicroscope. Magnification was set at ×20 to identify the location of bond failure and regulate the volume of remnant adhesive on enamel surface. Remnant adhesive material was evaluated by two investigators blindly according to modified classification of Olsen *et al.* (1997). An ARI of 1 corresponds to all adhesive on the tooth, an ARI of 2 corresponds to more than 90% of the adhesive on the tooth, an ARI of 3 corresponds to between 10% to 90% of the adhesive on the tooth, an ARI of 4 corresponds to less than 10% of the adhesive on the tooth, and an ARI of 5 corresponds to no adhesive on the tooth. In case of inconsistency between investigators for a specimen, the decision was made according to evaluation of another (third) investigator. Only the inconsistent data were presented to the third investigator as two options that were the scores of previous investigators. The evaluation of third investigator was also performed blindly. Final dataset were created from the data of third investigator in addition to the data of consistent scores of first and second investigators.

Fig. 2 Shear bond strength analysis with a universal testing machine.

STATISTICAL ANALYSIS

All statistical analyses were performed by using IBM SPSS Statistics version 22.0 (Chicago, IL, USA). The data distribution of normality was tested with the Shapiro-Wilk test and the Kolmogorov-Smirnov test. Inter-examiner reliability was evaluated with the Cohen's Kappa test. A Kappa value of 0.886 indicated a high reliability between first and second investigators. The comparison of SBS values between five groups was performed by Kruskal-Wallis test where a chi-square test was used to compare the groups with respect to ARI.

RESULTS

According to the Shapiro-Wilk test and the Kolmogorov-Smirnov test, data were not distributed normally. Kruskal-Wallis test showed that the median values of SBS were 6.36 (mean±SD = 8.06±6.33), 11.44 (mean±SD = 13.49±9.42), 5.68 (mean±SD = 6.75±4.58), 10.17(mean±SD = 11.35±6.55), and 2.62 (mean±SD = 2.92±2.57) for TXT, NC+etch, VF+etch, NC, and VF respectively (Fig. 3, Table 2). NC+etch group showed statistically the highest SBS and VF group showed statistically the lowest SBS with statistically significant difference between five groups ($p < 0.001$).

ARI showed statistically significant difference between five groups based on chi-square test ($p < 0.001$) and the result of chi-square test is given in Table 3. ARI 1 was observed in 81.3% of TXT group whereas 62.5% of NC+etch. ARI 1, 2, and 3 were equally distributed in VF+etch group (31.3%). ARI 5 was observed in 37.5% of NC and 62.5% of VF. The representative images for each group are given in Fig. 4 that refers ARI 1 in TXT and NC+etch groups, ARI 3 in VF+etch group, and ARI 5 in NC and VF groups.

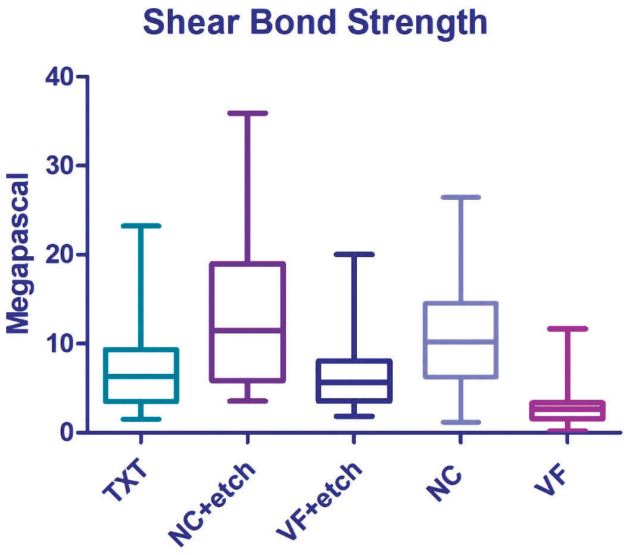

Fig. 3 Boxplot distribution of shear bond strength in megapascal between groups.

Table 2 The comparison of SBS between groups based on the results of Kruskal-Wallis test

Group	Minimum	Maximum	Mean	SD	Percentile			*n*	x^2	df	*p*
					25th	50th (Median)	75th				
TXT	0.98	14.89	8.06	6.33	2.26	4.08	6.01	16			
NC+etch	2.28	23.04	13.49	9.42	3.75	7.34	12.17	16			
VF+etch	1.20	12.83	6.75	4.58	2.28	3.64	5.19	16	30.426	4	0.001*
NC	0.76	16.96	11.35	6.55	4.02	6.52	9.32	16			
VF	0.11	7.50	2.92	2.57	1.01	1.68	2.15	16			
Total	0.11	23.04	8.51	7.17	2.17	3.97	7.39	80			

Note: *$p < 0.05$

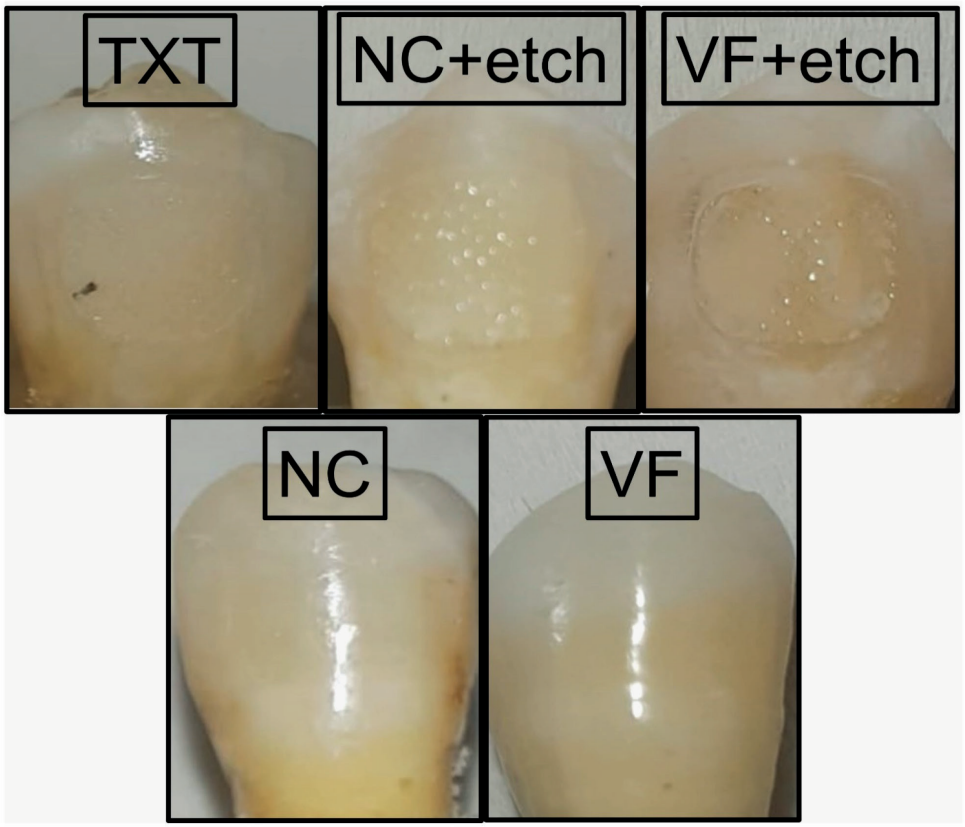

Fig. 4 Representative samples for each group for ARI evaluation.

DISCUSSION

TXT that belongs to total-etch system has been the gold standard for bracket bonding (Hellak *et al.*, 2016). However, decreased SBS of TXT was reported on rebonding process (Türköz *et al.*, 2010). Total-etch systems are technique sensitive, and the application process requires long time due to surface conditioning with etching. However, through recent advances in adhesive dentistry, these disadvantages were tried to be eliminated with new systems and materials. Self-adhering flowable composite materials, such as VF and NC, which consist of flowable composite and all-in-one bonding system are one of these recently developed materials with simpler application procedures (Vichi *et al.*, 2013). Both of these materials were preferred in the present study not only because of their reduced costs but also their easy handling features and simplified bonding protocols in addition to their non-cytotoxic effects (Kahvecioğlu *et al.*, 2021).

In the present study, SBS and ARI were compared between total-etch systems with two different products of self-adhering flowable composite materials with different application procedures.

Self-adhering flowable composite materials were not mainly produced for bracket bonding. Therefore, the application of these materials were not existing in the instructions of both flowable materials. According to instructions of VF, light curing was advised after rubbing a thin layer of material first and then applying the other layers. However, this light curing of the first layer is thought to prevent adaptation of bracket base to the surface. Therefore, the first light curing was omitted in the present study with anticipation of uneven surface under bracket base that prevents accurate replacement as applied in other studies (Goracci *et al.*, 2013; Valizadeh *et al.*, 2020). On the other hand, although the application of less than 2 mm of material was instructed for NC to the enamel surface, less than 0.5 mm was applied to enamel surface in order to ensure standardisation.

NC with additional etching showed the highest SBS followed by NC application without etching. The SBS values of NC+etch, NC, and TXT were compatible with the clinically acceptable minimum values (Reynolds, 1975; Sabah, 2011). However, SBS values of VF+etch, and VF groups were under these values. On the other hand, values more than 10 MPa were advised for successful clinical use (Lowder *et al.*, 2008). From this perspective, only NC+etch and NC groups showed an SBS exceeds 10 MPa.

In a previous study (Bahnasi *et al.*, 2013a; 2013b), sandblasted recycled orthodontic brackets were suggested to be used as an alternative to new brackets in order to reduce cost. Based on the comparative results of the previous study, only one time recycling was investigated in the present study. Although not only recycling but also repeated recycling groups showed clinically acceptable results in the previous study that used TXT, the group TXT showed lower SBS on rebonding process in the present study compared to previous study.

Another previous study reported a mean value of 5.9 MPa in initial bracket bonding for VF (Gungor *et al.*, 2016). In the present study, SBS median values were 5.68 and 2.62 in VF+etch and VF groups, respectively. The lower values could be explained by the design of present study that investigates SBS on not initial bonding but rebonding process. From the results of SBS in present study, it was hard to suggest any superiority between total-etch systems and self-adhering flowable composites on rebonding since one of the self-adhering flowable composites showed higher but the other self-adhering flowable composite showed lower bond strength. However, it can be inferred that NC, the novel self-adhering flowable composite material can be promising when used for rebonding process.

The contents of composite materials used in the present study were different from each other. NC includes 10-MDP and 4-META as functional monomers where VF includes GPDMA. Although both NC and VF were self-adhering flowable materials, the different contents of functional monomers could be the main reason for statistically different SBS and ARI. The 10-MDP and 4 META form strong ionic bonds with calcium of hydroxyapatite. Although GPDMA can etch enamel, low acidity of VF can cause insufficient micromechanical retention resulting in inadequate bond strength (Poorzandpoush *et al*., 2019).

During the temperature changes of the oral cavity, the adhesive materials are subjected to stresses which are thought to affect bond strength (Bishara et al., 2007). Therefore, thermocycling between 5°C–55°C was preferred in the present in vitro study, in order to imitate the oral environment for better evaluation.

The brackets used in the present study had mesh base structure. However, sandblasted bracket base was used in SBS analyses in order to evaluate SBS and ARI on repeated bonding procedure. A previous study showed that there was no difference between conventional mesh base and sandblasted base types regarding shear bond tests (Lugato *et al*., 2009). In the present study, bracket base design could have an effect depending on the standardisation problem due to manual sandblasting. Although sandblasted bracket base design could affect the SBS and ARI values for each specimen, the comparison overall results are thought to be affected minimally due to the usage of one type of bracket base with the same sandblasting protocol for each group.

ARI gives information about where the bond failure has occurred. According to the modified classification of ARI scoring, lower ARI refers to bonding failure between bracket base and adhesive material where higher ARI scores refer to bonding failure between adhesive material and enamel surface. In first situation, cleaning remnant material takes longer time while the risk of enamel fracture is less. However, in second situation, surface cleaning takes less time with higher risk of enamel fracture. In the present study, ARI was 1 in TXT and NC+etch which means bracket failure generally occurred between bracket base and adhesive material. The frequency in TXT group was higher than NC+etch group. Less penetration to sandblasted bracket base in TXT than the flowable material can be the reason for this when both ARI and SBS values were considered. Groups without additional etching procedures (NC and VF) showed higher ARI which refers to a bonding failure between enamel surface and adhesive material. Although both NC and VF showed the highest ARI frequency of score 5, the SBS of NC was secondly highest among all groups. From these perspectives, NC can be a superior alternative to VF when rebonding is planned. For both self-adhering flowable composites, additional etching for 20 seconds increased SBS of them while causing bracket failure at the bracket base-adhesive interface. Although the idea of additional etching is in contradiction with the logic of the invention of self-adhering flowable composite systems, better bond strength with additional etching on rebonding process can make it a preferable application procedure.

Although previous studies (İşman *et al*., 2012; Abdallah *et al*., 2013) have investigated VF on bracket bonding, none of them investigated VF on rebonding process. To the best of our knowledge, there was also no published research investigating SBS of NC on orthodontic bracket bonding procedure since it has started to be produced in recent years. The present study can contribute to the literature as the first study investigates both VF and NC on rebonding process.

SBS can be affected from previous application of bleaching and remineralisation agents to the tooth surface (Abe *et al*., 2011; Topsakal & Amuk, 2019; Azizi *et al*., 2020). However, study sample of the present study was lack of precise information about this

issue which is thought to be a limitation for the present study. Although the teeth used in this present study were all premolar teeth, each specimen was different from the other. Therefore, it would be difficult to achieve a precise standardisation. In the present study, the stereomicroscopic examination was performed before only first bonding, not before second bonding. Although the bonding was performed by an experienced clinician, stereomicroscopic examination before second bonding would contribute more precisely to the results through checking the smooth, intact enamel surface cleaned with a tungsten carbide burr. On the other hand, obtaining a standardised bracket base after debonding and sandblasting could be questionable which may affect SBS due to bracket base deformation, undercuts, and changes of mesh design. Therefore, SEM evaluation would contribute to evaluation of SBS in further studies. Besides, including the teeth with similar age would contribute to the study by eliminating the confounding factors as tooth age.

In vitro design of the study was another limitation of the present study. Further in vivo studies in a natural oral environment could offer more reliable results.

CONCLUSION

Within the limitations of present study; additional etching before application of self-adhering flowable composite materials increased bond strength. Self-adhering flowable composite materials leave less remnant material on tooth surfaces when they are used in direction of the brand's instructions. When compared to other materials, NC, the novel self-adhering flowable composite material, showed the highest SBS on rebonding process therefore, it can be a promising alternative to TXT which is the gold standard. Retrieved brackets can be used with the novel self-adhering flowable composite material, NC, during clinical management of the patients.

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