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Evaluation of Shear Bond Strength and Adhesive Remnant Index of New-Generation Adhesive-Coated Bracket Systems in Comparison With Traditional Systems

Yeni Nesil Adeziv Kaplı Braket Sistemleri ve Geleneksel Sistemlerin Bağlanma Dayanımı ve Artık Adeziv İndeksinin Değerlendirilmesi

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ABSTRACT

Objective: To evaluate the shear bond strength (SBS) and the adhesive remnant index (ARI) of different traditional orthodontic adhesive systems and newly developed pre-coated adhesive systems.
Methods: A total of 50 human maxillary premolars were bonded with Clarity advanced ceramic brackets using APC™ Flash-Free, APC™ PLUS, Transbond™ XT Light Cure, Opal® Bond™MV and, Blugloo™ adhesives. All samples underwent thermo-cycling. The SBS was determined using a testometric machine. A stereomicroscope was used to evaluate the adhesive remnant on debonded enamel surface. Differences among the adhesives were tested for statistical significance.
Results: Blugloo™ group had the highest SBS (22.69 ± 9.14 MPa). However, there was no significant difference in mean SBS among the groups (*P*<.05). The Flash-free adhesive group had a significantly lower ARI score than Opal® Bond™MV and, Blugloo™ groups (*P*<.001).
Conclusion: All experimental groups provided clinical bond strength higher than required. The flash-free adhesive group resulted in lower adhesive remnant, this saves time for the clinician.
Key words: Adhesive-coated bracket systems, shear bond strength, traditional brackets

ÖZ

Amaç: Farklı geleneksel ortodontik adeziv sistemlerin ve yeni geliştirilen önceden kaplanmış adeziv sistemlerin makaslama bağlanma dayanımını (SBS) ve artık adeziv indeksini (ARI) değerlendirmektir.
Yöntem: Toplam 50 insan üst küçük azı dişi, APC™ Flash-Free, APC™ PLUS, Transbond™ XT Light Cure, Opal® Bond™MV ve Blugloo™ adezivler kullanılarak Clarity advanced seramik braketlerle yapıştırıldı. Tüm örneklere termal-siklus uygulandı. SBS, bir testometrik makine kullanılarak belirlendi. Mine yüzeyindeki artık adezivi değerlendirmek için bir stereomikroskop kullanıldı. Yapıştırıcılar arasındaki farklılıklar istatistiksel anlamlılık açısından test edildi.
Bulgular: Blugloo™ grubu en yüksek SBS'ye (22,69 ± 9,14 MPa) sahipti. Ancak gruplar arasında ortalama SBS açısından anlamlı bir fark yoktu (*P*<.05). Flash-free adeziv grubu, Opal® Bond™MV ve Blugloo™ gruplarına göre anlamlı derecede daha düşük ARI skoruna sahipti (*P*<.001).
Sonuç: Tüm deney grupları, gerekenden daha yüksek klinik bağlanma dayanımı sağlamıştır. Flash-free adeziv grubu daha düşük adeziv artığına yol açmıştır, bu da klinisyene klinik kullanımda zaman kazandıracaktır.
Anahtar kelimeler: Adeziv-kaplı braket sistemleri, bağlanma dayanımı, geleneksel braketler

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INTRODUCTION

Despite the ever-increasing popularity of aligner therapy, fixed treatments with bands and brackets are still the most preferred technic in orthodontics. When classical brackets are used in the treatment, the composite is manually applied to the base of the bracket in a thin and homogeneous manner after that the bracket is placed on the facial surface of enamel at an appropriate position. Then the excess adhesive flowing from the margin of the bracket is removed (flash clean-up) and composite is polymerized. The flash clean-up provides protection against caries by reducing the area of dental plaque accumulation during the prolonged period of orthodontic treatment.[1,2]

Orthodontic bonding is time-consuming for clinicians, so it is important to simplify this procedure while optimizing bonding strength. Recently, 3M Unitek (Monrovia, California, USA) has launched the novel APC Flash-Free brackets to facilitate the bonding process.[3] The claimed advantages of these pre-coated brackets include the elimination of flash clean-up, fewer steps in the bonding process, and enhanced bond strength with less error.[3] Lee and Kanavakis[4] report that the bonding time was significantly lower in flash-free brackets compared to traditional bracket systems. In the same study, the bond strength was found to be significantly higher in APC Flash-free brackets compared to the Clarity Advanced bracket group, in which the composite is manually applied to the base of the bracket.

Ease of operation, bond strength, and accessibility are essential properties for orthodontic bonding systems in clinical practice. In the study by Reynolds, it was reported that the appropriate bond strength ranges from 5.6 MPA to 7.8 MPa. [5] Bishara reported that the major problem for safe debonding is excessive bond strength in ceramic brackets.[6] The debonding force applied to the ceramic bracket leads to the break-up of the bond between enamel and adhesive and cracks when enamel fails to resist sufficiently. Currently, many orthodontic bonding systems ensure sufficient bond strength. However, to the best of our knowledge, there is no study reporting a standardized comparison between recent pre-coated bracket systems, which shorten duration of bonding procedure, and traditional adhesive systems, which are widely used in orthodontic clinics.

In this in vitro study, it was aimed 1) to compare bond strength among adhesive materials from different brands and pre-coated brackets (Flash-free and APC-Plus); and 2) to compare the amount of adhesive remnant after debonding. The null hypothesis is that flash-free brackets will leave less adhesive remnant and have better bond strength compared to other adhesives.

METHODS

Specimen Preparation and Grouping

According to power analysis; with an effect size of 0.6190, an alpha level of 0.05, and a power of 0.90; it was assigned that a minimum of ten subjects in each group was required for five groups (version 3.1.9.3, G*Power; *HHU* Düsseldorf, Germany). Fifty newly extracted human maxillary premolars were collected and cleaned with a scaler to remove soft tissue and debris.[7] The criteria for selection were intact buccal enamel, no caries or cracks, no restorations and no prior orthodontic bonding. Until the test time the teeth were stored in 0.1% thymol solution for inhibition of bacterial growth at room temperature (maximum of two weeks).[4]

The specimens were randomly divided into five groups (APC Flash-free, APC Plus, Transbond XT, Opal, Blugloo), each containing ten teeth and five different adhesives were used for each (Table 1). 3M Clarity advanced brackets were used for all groups. Each tooth was individually embedded in a self-curing acrylic resin block exposing crown for bonding procedures.

Table 1. *Experimental groups and bonding materials used according to groups.*

Groups	n	Bracket	Primer	Adhesive
APC Flash-Free	10	Clarity™ Advanced	Transbond™ XT Primer	APC™ Flash-Free
APC Plus	10	Clarity™ Advanced	Transbond™ XT Primer	APC™ PLUS
Transbond XT	10	Clarity™ Advanced	Transbond™ XT Primer	Transbond™ XT Light Cure Adhesive
Opal	10	Clarity™ Advanced	Opal® Seal™	Opal® Bond™MV
Blugloo	10	Clarity™ Advanced	Ortho Solo™ Primer	Blugloo™

Methodology

Enamel preparation. All teeth were polished with a flour-free paste, then each rinsed with water and air-dried. A %37 phosphoric acid gel (3M™ Dental Products, USA) was applied 30 seconds to the buccal surface of the enamel. Then enamel surface rinsed with water for 20 seconds and dried with compressed air. The frosty white appearance was the criteria of a successful acid etching. After surface preparation a thin coat of primer was applied to enamel surface and air-thinned with gentle air. Transbond™ XT Primer was applied for APC Flash-free, APC Plus and, Transbond XT groups; Opal® Seal™ primer was applied for Opal Bond MV group and; Ortho Solo™ primer was applied for Blugloo group (Table 1). The primer was cured with light-emitting diode device (LED) for 10 seconds with a power of 1000 mW/cm^2.

Bonding procedure. Maxillary premolar Clarity™ Advanced ceramic brackets (3M Unitek) were bonded to all specimens by a single operator. The same bonding steps was applied to all non-pre-coated groups with different agents. A thin and homogeneous layer of adhesive was placed onto the brackets' base, and the brackets were placed in the ideal position of the buccal enamel. The brackets were then compressed 10 seconds with a force of 300 g by using a force gauge (P1025-00, Leone™, Italy) for standardization.[8] Excessive adhesive resin around the bracket was removed carefully with a dental probe. LED light was used 10 seconds from distal and mesial sides of each bracket for adhesive polymerization.

APC Flash-free and APC Plus groups has some differences in application of brackets. These precoated brackets, which requires no adhesive application onto the base or no removal of excess adhesive material, directly placed to the ideal position of buccal enamel surface, then compressed 10 seconds with a force of 300 g (P1025-00, Leone™, Italy). Adhesive material was light-cured with the same protocol of non-precoated groups.

Thermocycling was performed for simulating six months of oral thermal environment. All specimens underwent thermocycling (Julabo GmbH, FT 400, Seelbach, Germany) including 5000 cycles at 5 and 55 °C with a dwell time of 30 seconds.[9] Then, they were stored in distilled water at 37°C for 24 h,[7] and subsequently performed shear bond test on Testometric machine (Testometric M500 25kN, Rochdale, UK).

Shear Bond Strength

The specimens were fixed in the metal sample holder of lower part of the testing machine. Bracketed buccal surface of the teeth was positioned parallel to the moving upper part of the machine. The knife edged upper part of shearing device was placed perpendicularly between bracket wing and base with motion direction parallel to vestibular surface of teeth and bracket base. The test was initiated with no force on bracket by shearing device which had slight contact with bracket. The crosshead velocity for this device was set as 1 mm/minute.

During test procedure, the increase in shearing force was monitored from screen of test device and maximum bonding strength (the strength at time of bracket debonding) was recorded (Newton, N). The maximum value of shearing force was divided by surface area of bracket body, indicating strength at unit area (MPa=N/mm^2).[7] In this study, Clarity Advanced ceramic brackets were used in all groups and surface area of this bracket body is 11.694 mm^2 according to the manufacturer (3M) (4).

Evaluation of Adhesive Remnant Index (ARI)

After bracket removal, the residual adhesive on the site of bonded enamel was evaluated using a stereomicroscope (Nikon SMZ800) under 10X magnification. Modified Adhesive Remnant Index (ARI) as described by Bishara and Trulove was used for scoring and was performed by the same examiner at two different times with one month interval.[10] This scale ratings from 1 to 5.

1, all adhesive remains on the enamel

2, more than 90% of the composite remained on the enamel

3, more than 10% but less than 90% of the composite remained on the enamel

4, less than 10% of composite remained on the enamel

5, no adhesive left on the enamel.

Statistical Analysis

Shapiro-Wilk test was used to assess normal distribution of quantitative parameters. One-way ANOVA test was used to compare data with normal distribution among groups while Kruskal-Wallis and All pair-wise multi-comparison tests were used to compare data with skewed distribution. Intra-observer agreement was assessed using Kappa coefficient. As reported by Landis and Koch,[11] the strength of agreement was rated as follows: 0.01-0.20, poor; 0.21-0.40, slight; 0.41-0.60, moderate; 0.61-0.80, substantial; and 0.81-1.00, almost perfect.

Descriptive statistics are presented as median, Q1 and Q3. All statistical analyses were performed using SPPS for Windows version 24.0 (SPSS, Chicago, IL, USA). p <0.05 was determined as significance level.

RESULTS

Table 2 presents shear bond strength after thermocycling procedure. The highest SBS value was recorded in Blugloo group (22.69±9.14 MPa) while lowest SBS value was observed in APC Flash-free group (17.51±6.03 MPa). However, no significant difference was found in mean SBS among study groups using different adhesives and primers (p=0.579).

Table 2. *Intra-group comparison of SBS (MPa) with one-way ANOVA test*

Groups	Mean ± SD	Min-Max	*p* value
APC Flash-Free	17.51 ± 6.03	10.2-27.5	0.579
APC Plus	20.50 ± 7.03	8.7-32.6	
Transbond XT	18.84 ± 8.15	9.3-29.6	
Opal	18.56 ± 6.81	9.4-28.3	
Blugloo	22.69 ± 9.14	11.8-38.8	

P value was obtained from one-way ANOVA test. SD; standart deviation

Table 3 presents Kappa values for intra-observer agreement of ARI scores obtained at two different time points. The intra-observer agreement was found to be substantial in APC Flash-free, APC Plus, Transbond XT and Opal groups while it was found to be almost perfect in Blugloo group. In all groups, intra-observer agreement was substantial of higher for ARI scores obtained in two different time points.

When mean modified ARI scores were compared after debonding, the amount of residual adhesive was significantly lower in APC Flash-Free group than those in Opal and Blugloo groups (P<.001). No statistically significant difference was observed between the other groups (Table 4).

Table 3. Kappa values for intra-observer agreement

Groups	Modified ARI	M	Q1	Q3	Kappa (CI 95%)
APC Flash-Free	ARI Score 1	1.00	1.00	2.00	0.610 (0.142 1)
	ARI Score 2	1.00	1.00	1.00	
APC Plus	ARI Score 1	4.00	4.00	4.00	0.792 (0.465 1)
	ARI Score 2	4.00	4.00	4.00	
Transbond XT	ARI Score 1	4.00	4.00	4.00	0.615 (0.300 1)
	ARI Score 2	4.00	4.00	4.00	
Opal	ARI Score 1	4.00	4.00	4.00	0.610 (0.140 1)
	ARI Score 2	4.00	4.00	4.00	
Blugloo	ARI Score 1	4.50	4.00	5.00	1 (1 1)
	ARI Score 2	4.50	4.00	5.00	

M; Median, CI; confidence interval, Q1 Quartile1(P25), Q3 Quartile3(P75)

Table 4. Comparison of mean ARI scores (M) among experimental groups

Groups	M	Q1	Q3	*p* value	Pairwise comparison
APC Flash-Free	1	1	1.5	<0.001	APC Flash-Free < Opal
APC Plus	4	4	4		APC Flash-Free < Blugloo
Transbond XT	4	4	4		
Opal	4	4	4		
Blugloo	4.5	4	5		

P value was obtained from Kruskal Wallis test. M, median; Q1, Quartile1 (P25); Q3, Quartile3 (P75)

DISCUSSION

The adequate enamel-bracket bonding strength is one of the prerequisites for success of orthodontic treatment. For this purpose, several adhesive materials have been produced by different companies. Recently, pre-coated brackets introduced by 3M provides sufficient bonding while shortening duration of bonding procedure.[3,4] However, higher cost of pre-coated brackets is a disadvantage.

In our study, Clarity advanced ceramic brackets were bonded to enamel using different adhesive systems (APC™ PLUS, Transbond™ XT Light Cure Adhesive, Opal® Bond™MV and Blugloo™) in experimental groups. The temperature alterations in intraoral environment were simulated using thermocycling, corresponding to 6 months; the SBS was assessed thereafter. The aging process simulating 6 months period between bonding and debonding procedures suggests that a realistic experimental environment was developed in our study.

The enamel preparation, type of adhesive used in bonding, debonding technique, time from bonding to debonding and storage conditions of samples are the factors that influences on bonding strength of brackets. In our study, bonding phases and debonding procedures were standardized across all groups; excluding factors which may impact SBS values.

In current study using different adhesives, the highest SBS value was recorded in Blugloo group (22.69±9.14 MPa) while the lowest SBS value was observed in APC Flash-free group (17.51±6.03 MPa). No significant difference was detected in SBS among groups. The Blugloo agent used in our study is an adhesive specially designed for ceramic bracket bonding. This may explain the highest bonding strength with this adhesive. On the other hand, flash-free systems and traditional Transbond XT and Opal groups provided comparable strength values.

Gabriela MM *et al.* used similar bonding and debonding technique in their study and found that SBS was 21.77 MPa in APC Flash-free group (n=15), 27.11 MPa in APC Plus group (n=15), and 26.26 MPa in Transbond XT group.[12] Again, in a similar study, Ansari MY *et al.* found that SBS was 20.13 MPa in APC Flash-free group (n=10) and 27.26 MPa in Transbond XT group (n=10).[13] In our study, the SBS value was found to be lower than those in above-mentioned studies which employed similar techniques other than thermal-cycling. The difference in SBS values suggested thermocycling procedure reduces bonding strength.

In the study in which enamel prepared using self-etch primer, Lee and Kanavakis[4] found that SBS was 13.7 MPa in APC Flash-free group, 10.4 MPa in Transbond XT group and 10.8 MPa in APC Plus group. In that study, debonding test was performed using shear tension over wire attached to bracket wings. The SBS values were less than those observed in corresponding groups in our study. This difference may be due to different debonding method or self-etch primer use in the study by Lee and Kanavakis.

In the literature, there are studies reporting different bond strength values;[14-17] however, it will be meaningless to perform comparison with studies using different experimental design. In addition, in all adhesive types, we observed the bonding strength higher than optimal bracket bonding strength (5.9-7.8 MPa) as described by Reynolds.[5]

The modified ARI is a 5-points scale, which is commonly used to assess amount of adhesive residue over enamel. In this study, adhesive remnant scored twice (by one-month interval) by the same observer and intra-observer agreement was evaluated between two score using Kappa coefficient. The intra-observer agreement was found to be high in all experimental groups, which may be associated to experience of observer and eligibility of stereomicroscope for this assessment. The lower ARI scores indicate greater amount of residual adhesive on enamel surface that is thought to be concentration of debonding strength at bracket-adhesive interface while the higher scores indicate greater amount of residual adhesive over the base of bracket that is thought to be force concentration at adhesive-enamel interface.

In our study, lowest ARI score was found in APC Flash-Free group. It was lower than those in APC Plus and Transbond XT groups but did not reach statistical significance; however, it was significantly lower than those in Opalbond and Blugloo groups. After debonding, adhesive breakage occurring at bracket-adhesive interface decreases risk for enamel injury, although the removal of excess adhesive over enamel is time-consuming. In our study, the breakage more commonly occurred at bracket-adhesive interface in APC Flash-Free group which showed low ARI score while breakage occurred within adhesive resin in APC Plus, Transbond XT and Opal groups. In Blugloo group, the highest mean ARI score (4.5) showed that breakage occurred within resin in some teeth while at resin-enamel interface in others in this group. In addition, highest SBS value recorded in Blugloo group suggest that Blugloo adhesive can cause enamel cracks and fractures. However, there was no considerable number of enamel injury in any groups in our study.

In a study comparing adhesive remnant between precoated and uncoated brackets, Vicente and Bravoreported significantly lower residue over the enamel in APC Plus group.[18] On contrary, we observed the highest amount of residual adhesive in pre-coated APC Flash-free group. In another study comparing Flash-free and APC II adhesive coated appliance systems, Grrunheid *et al.* reported that the amount of residual adhesive over enamel was almost doubled in Flash-free group when compared to APC II system.[19] Similarly, Foersch *et al.*[20] compared APC Flash-Free and APC Plus systems and found that ARI score was 2.0 in APC Flash-Free group and 2.8 in APC Plus group. In both studies, lowest ARI score was reported in Flash-Free groups in agreement without study. These findings shows that flash-free systems are safe for enamel in bracket debonding; however, they prolong chair-time during debonding procedure.

In a recent study by Akl *et al*.,[21] no significant differences were found between conventional and APC Flash-Free brackets for shear bond strength. In the same study ARI score for APC Flash-Free brackets was higher with no significant difference between the conventional system and APC brackets.

In the present study, there was no significant difference in mean SBS values among groups but ARI score was significantly lower APC Flash-Free group. Thus, no significant correlation was detected between ARI score and SBS values of these five adhesives. These results show that the part of the null hypothesis of the study related to ARI is correct, but the part of the null hypothesis related to SBS cannot be confirmed.

CONCLUSION

In this in vitro study, following conclusions were drawn:

1. Highest SBS value was observed in Blugloo adhesive group.
2. All pre-coated and traditional adhesive systems used in this study had sufficient SBS for orthodontic treatment.
3. Traditional adhesives rather than pre-coated adhesive system ensure less adhesive remnant over the enamel surface in debonding; thus, they contribute shortening debonding time.
4. APC Flash-Free adhesive system is recommended to minimize enamel cracks which may occur debonding procedure in ceramic brackets.

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