ORIGINAL RESEARCH

Influence of Primer Pre-curing and Co-curing on Shear Bond Strength of Orthodontic Brackets Using Three Light-cure Adhesive Systems: An *In Vitro* Study

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Abstract

Aim: This study aimed to evaluate the shear bond strength (SBS) of orthodontic brackets with primer pre-curing and co-curing using three light cure adhesive systems.

Materials and methods: In this *in vitro* study, 102 extracted premolar teeth mounted on self-cure acrylic resin blocks were separated into six groups based on primer pre-curing and co-curing with each group receiving stainless steel orthodontic premolar brackets bonded to the buccal surfaces. The following adhesives were used: Transbond XT (3M Unitek, CA, USA), Orthofix (Anabond Stedman, India), and Enlight (Ormco, India). In the groups with pre-curing, the primer was pre-cured for 20 seconds while in the groups with co-curing, the primer and adhesive were cured together. Shear bond strength tests and Adhesive Remnant Index (ARI) were assessed followed by an scanning electron microscope (SEM) view (×3000) of the enamel surface after debonding. Statistical analysis was done using a one-way analysis of variance (ANOVA) test.

Results: The descriptive statistics in the pre-cured groups showed a statistically significant difference. The highest mean SBS was observed for group I, i.e., Transbond XT with primer pre-curing (20.56 ± 3.22 MPa). The lowest mean SBS was for group IV, i.e., Orthofix with primer co-curing (7.57 + 0.49 MPa). The results of ANOVA revealed a significant difference among the groups. The ARI scoring and the SEM analysis also confirmed this finding.

Conclusion: Shear bond strength of orthodontic brackets with primer pre-curing showed a better bond strength than brackets with co-curing. The ARI data suggested that the majority of bracket failure happened at the resin–bracket interface. Scanning electron microscope analysis also confirmed the ARI and SBS findings.

Clinical significance: During the bonding of orthodontic brackets, the primer can be co-cured where the primer and adhesive resin are cured simultaneously or pre-cured where the primer is cured separately. Most orthodontic clinicians to save time co-cure primer. Both these methods affect the SBS of brackets.

Keywords: Bonding, Co-curing, Light cure adhesive, Pre-curing, Shear bond strength.

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Introduction

Since Buonocore's invention of the acid-etching technique in 1955, which streamlined the bonding process, orthodontic bonding of brackets has become a commonly accepted clinical procedure. The use of composite resin as a bonding medium is one of the most significant advancements in orthodontics in the last three or four decades; it was first introduced by Newman in 1965. Conventional adhesive systems use three different agents (an enamel conditioner, a primer solution, and an adhesive resin) in the process of bonding orthodontic brackets to the enamel.[1] Primer is usually an unfilled resin that is employed as part of the bonding process particularly with light-cured composites. Its main goal is to penetrate the enamel surface and improve the final bond's efficacy.[2] The acidic part of the primer dissolves the smear layer and incorporates it into the mixture. It also demineralizes and encapsulates collagen fibers and hydroxyapatite crystals. This simultaneous conditioning and priming allows penetration of the monomer into the enamel.[1]

Chapman et al.[3] observed that pre-curing of self-etch adhesives before curing the resin composite produced significantly greater bond strength to dentin. The curing technique had no significant effect on the SBS of self-etching adhesives to the enamel. Vishwanathan et al.[4] in their study found that the curing sequence had no significant effect on the SBS of adhesives on the primary enamel. Pre-curing the primer before curing composite resins produced greater SBS to primary dentine. Verma et al.[5] conducted a study on the estimation of ARI between Light-Cure (Enlight, Ormco) and Dual cure composite (Phase II dual cure, Reliance Ortho) and found that most of the bond failures in both groups were between the tooth surface and adhesive, and a very small amount of adhesive remnant was left on the enamel surface.

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Previous literature has cited many studies testing the adhesive strength of Transbond XT and Enlight adhesives.[1] Orthofix (Anabond Stedman) is a bisphenol A-glycidyl methacrylate (Bis-GMA)-based light-cure orthodontic adhesive that has been "Made in India" for orthodontic bonding. Due to the widespread usage of the Orthofix (Anabond Stedman) light-cure adhesive systems by clinicians for orthodontic bonding, the SBS of the Orthofix orthodontic adhesive was compared to the shear bond strength of Transbond XT and Enlight adhesive systems.

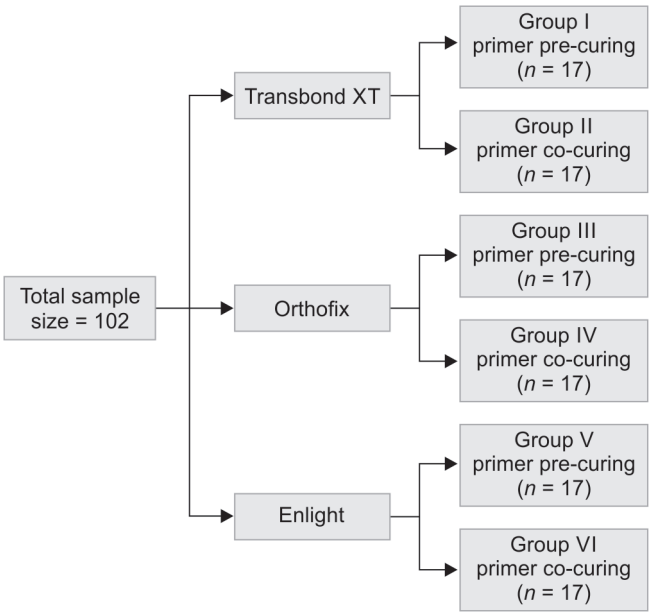
This study aimed to evaluate the SBS of orthodontic brackets with primer pre-curing and co-curing using the three light cure adhesive systems.

Materials and Methods

The comparative *in vitro* study was conducted at the Department of Orthodontics, MES Dental College, Perinthalmanna, India. A total of 102 maxillary first premolar teeth were collected as part of therapeutic extraction from patients being treated in the department. The study period was from January 1, 2020 to January 1, 2021.

The collected samples were divided into six groups of 17 teeth for each testing variable (Flowchart 1 and Table 1). The approval was obtained from the Institutional Ethics Committee of MES Dental College (IEC/MES/58/2019).

Flowchart 1: Sample allocation flowchart



- Group I: Bracket bonded using Transbond XT with primer pre-curing
- Group II: Bracket bonded using Transbond XT with primer co-curing
- Group III: Bracket bonded using Orthofix with primer pre-curing
- Group IV: Bracket bonded using Orthofix with primer co-curing
- Group V: Bracket bonded using Enlight with primer pre-curing
- Group VI: Bracket bonded using Enlight with primer co-curing

Sampling Criteria

Exclusion Criteria:

- Carious teeth
- Hypoplastic teeth
- Fractured teeth
- Fluorosed teeth

The extracted teeth were cleaned to remove any traces of blood by rinsing them under tap water. The teeth were then mounted on self-cure acrylic blocks into groups based on color coding for easy identification (Table 1). The samples were stored in an airtight and humid environment to prevent dehydration.

Bonding

The mounted teeth were acid-etched with 37% phosphoric acid (Eazetch, Anabond Stedman) for 30 seconds, rinsed under running water for 20 seconds, and then dried with compressed air. The samples were then inspected for the characteristic dull, white, frosted appearance of adequately etched enamel. The manufacturer-supplied primer was applied to the teeth in each color-coded group and two primer curing techniques were done: primer pre-curing and primer co-curing (Flowchart 2).

Primer Pre-curing

In the groups which required pre-curing (Groups I, III, and V), the recommended primer was air-thinned and then cured for 20 seconds. The group-specific adhesive resin was applied to the base of Ormco Mini 2000 stainless steel brackets and positioned on the buccal surface of the teeth. Excess bonding material was carefully removed and the mesial and distal sides were light cured for 20 seconds each, using an LED curing unit (KODEN).

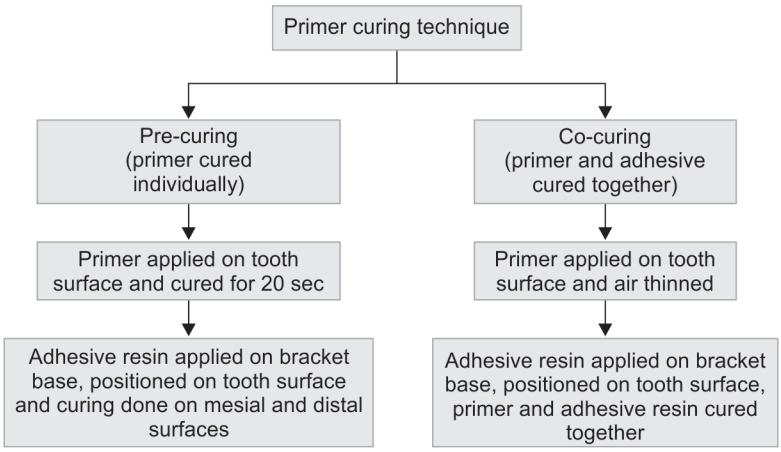
Primer Co-curing

In the groups in which co-curing was planned (Groups II, IV, and VI), the primer was applied on the tooth surface and air-thinned followed by adhesive resin-coated bracket placement and removal of excess material. The primer and adhesive resin were cured simultaneously on both mesial and distal aspects.

Table 1: Color-coded testing groups

Group	*Sample size*	*Color*	*Composite*	*Primer Pre-curing/co-curing*
Group I	17	White	Transbond XT	Pre-curing
Group II	17	Yellow	Transbond XT	Co-curing
Group III	17	Orange	Orthofix	Pre-curing
Group IV	17	Dark green	Orthofix	Co-curing
Group V	17	Blue	Enlight	Pre-curing
Group VI	17	Light green	Enlight	Co-curing

Flowchart 2: Flowchart for workflow



Shear Bond Testing

Shear bond tests were conducted using a Universal Testing Machine (Shimadzu Autograph AG-IS) with a cross-head speed of 1 mm per minute. The SBS measurements were measured in Newton and then converted to Megapascal (MPa). During testing, the facial surface of each tooth was placed parallel to the force direction. A flattened steel rod was used to apply force on the bracket teeth interface. A computer connected to the testing machine recorded the load at the bracket failure site. The SBS measurements were measured in Newton and then converted to MPa by dividing the force by the bracket's base area. As stated by the manufacturer, the bracket's base area was 9.63 mm^2.

ARI and SEM Analysis

After debonding, the enamel surface was examined visually and classified from 0 to 3 according to ARI. The representative debonded teeth from each group were then prepared for the SEM observation. Briefly, the teeth were dried by heating to remove any moisture and then mounted on aluminum stubs for gold sputtering. The mounted teeth were then sputtered with 3–6 nm of gold at 10 mA current for 90 seconds.

The gold-coated teeth were then placed for SEM analysis (FESEM, JSM 7610F PLUS). The observations were performed at 15 kV, at a working distance ranging from 9.5 to 13.5 mm, capturing images at ×3000 magnification (Fig. 1).

Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences 22.0 (SPSS Inc., Chicago, IL, USA) and the level of significance was set at $p < 0.05$. Descriptive statistics were performed to assess the mean and standard deviation of the respective groups. The normality of the data was assessed using Shapiro–Wilk test. Inferential statistics to find out the difference between the groups was done using one-way ANOVA and Tukey's *post-hoc* test. The proportion of ARI scores was done using the Chi-square test.

Results

Descriptive statistics, including the mean, standard deviation, and minimum and maximum values of the SBS for all experimental groups are presented in Table 2. Figure 2 shows the comparison of mean SBS values. The highest mean SBS was observed for group I, i.e., Transbond XT with primer pre-curing (20.56 + 3.22 MPa). The lowest mean SBS was for group IV, i.e., Orthofix with primer co-cured (7.57 + 0.49 MPa). The differences between the SBS values of six groups were statistically significant as the one-way ANOVA (Table 3) between the groups showed statistically significant value ($p <$ 0.0001). Pair group comparison using Tukey's honestly significant difference (HSD) test revealed that significant difference exists between most of the groups except groups I and V, groups I and VI, groups II and VI, and groups V and VI. From this, it can be inferred that composites Transbond XT and Enlight showed no statistically significant difference in mean SBS with primer pre-curing or co-curing. The mean SBS of Transbond XT and Enlight showed statistically significant difference when compared with Orthofix light-cure composite both with pre-curing and co-curing (Table 4).

ARI data showed a different pattern of enamel–adhesive and bracket–adhesive interface failure in all groups. Groups I and VI showed highest percentage of score 2 (58% and 35%, respectively); Groups III, IV, and V have highest percentage of score 1 (64%, 52%, and 47%). Groups I and II showed bracket–adhesive interface failure confirming that Transbond XT has better bond strength to tooth which could be due to the formation of resin tags (Table 5).

The SEM analysis of representative tooth from each group under ×3000 magnification (Fig. 1) confirmed with the ARI score obtained in each group. Group I had high score of ARI, which means that the failure occurred at bracket–adhesive interface leaving more adhesive on the tooth. Group IV had the lowest ARI score, which means the failure occurred at the enamel–adhesive interface.

Discussion

The bonding system for placing orthodontic brackets has proven to be dependable over time, but the procedures haven't changed much since Buonocore and Newman first introduced it in the 1950s and 1960s. The techniques create an etched surface on the enamel, which when washed and cured, creates a high-energy surface that resin can easily wet. The etched surface is flooded with liquid resin, which forms resin tags that provide mechanical retention. A weaker retention area is generated if anything prevents the flow of liquid resin or its curing. Filled resin is pressed onto the back of the orthodontic bracket, which has a mechanically retentive surface followed by curing it. Primer is usually an unfilled resin that is employed as part of the bonding process particularly with light-cured composites. Its main goal is to penetrate the enamel surface and improve the bond strength.[6–9]

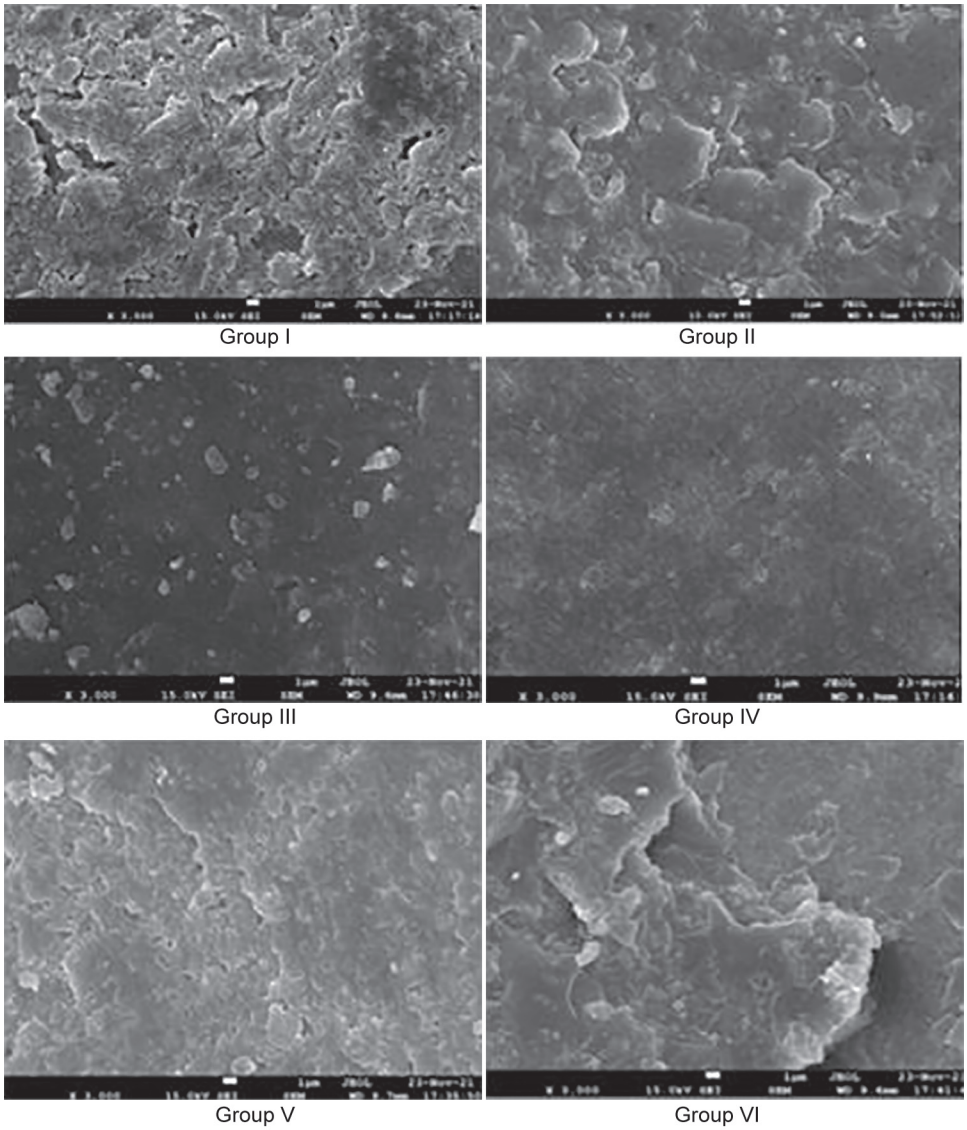


Fig. 1: Enamel surface of the tooth at ×3000 magnification under SEM showing resin remnants

Table 2: Descriptive statistics of SBS in MPa for all experimental groups

Group	*Mean (MPa)*	*SD*	*Min. (MPa)*	*Max. (MPa)*
Group I	20.56	3.22	9.237	30.396
Group II	16.62	4.64	6.58	90.86
Group III	11.67	2.89	5.62	21.986
Group IV	7.57	0.49	4.59	10.85
Group V	20.197	4.41	10.83	29.87
Group VI	19.56	2.91	10.48	29.58

The bond strength should be ideal, not excessive or insufficient. Excessive bond strength causes enamel damage during debonding, whereas insufficient bond strength causes frequent bond failures during treatment. According to Reynolds,[10] the optimal bond strength is between 6 and 8 MPa. Rapid breakthroughs in material science have led to more advanced materials, making direct bonding more precise, practical, and time saving.

The Transbond XT composite is one of the most often used adhesive solutions in orthodontics. Many research have been conducted to test its adhesive strength. Except in exceptional clinical conditions, Hellak et al.[11] claim that Transbond XT with a traditional acid-etching procedure is still the gold standard for bonding brackets to enamel.

In the present study, Transbond XT with primer pre-curing showed the highest mean SBS (20.56 + 3.22 MPa) whereas Orthofix with primer co-curing showed the lowest mean SBS (7.57 + 0.49 MPa). This investigation found no significant difference in the SBS between the two light-cured composite materials Transbond XT and Enlight with primer pre-curing although Enlight with primer co-curing showed a slightly higher mean SBS value than Transbond-XT with primer co-curing.

A study conducted by Rohmetra et al.[12] in which Orthofix (with and without primer) showed the SBS equivalent to Transbond XT, which ranged from 5.15 to 12.60 MPa (mean = 8.75 MPa), which are similar to the study conducted by Talwar et al.[13] in which the SBS values of Orthofix ranged from 5.872 to 11.46 MPa

(mean = 8.815 MPa). In the study conducted by Oesterle et al.[14] in 2004, there were no statistically significant differences between the bond strengths for either adhesive with the primer cured or uncured before bracket placement at either the 30-minute or 24-hour test times.

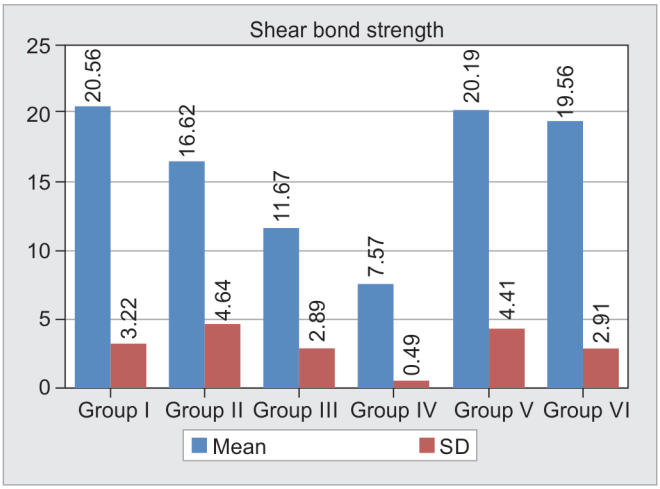


Fig. 2: Comparison of the mean SBS

Table 3: One-way ANOVA

	Sum of squares	*df*	*Mean squares*	*F*	*Sig*
Between groups	2400.6836	5	480.1367		
Within groups	1094.5024	96	11.4011	42.113	0.0001*
Total	3495.1860	101			

*$p < 0.05$ is statistically significant

Bradburn and Pender[15] demonstrated higher bonding strengths by pre-curing the filled resin using light. High bond strength values (16.77 MPa) were obtained in the conventional bonding procedure of primer pre-curing with Transbond XT in a study conducted by Tutika et al.[16] Shon et al.[17] also researched on primer pre-curing and found that primer precuring had the strongest bond (12.53 MPa), whereas the no pre-curing group had the worst bond (5.58 MPa). The high bond strength values were as a result of the formation of resin tags into the etched enamel surface. Vukelja et al.[18] in 2021 concluded from their study that co-curing technique resulted in lower bonding strength values in regards to a conventional method.

The quantity of adhesive left on the tooth after debonding was measured using an ARI technique developed by Artun and Bergland.[19] The ARI data in this investigation revealed a varied pattern of dental bracket failure in each group. The difference between the groups was significant (p-value = 0.0001). The highest percentage of score 2 was found in groups I and VI (58% and 35%, respectively); the highest percentage of score 1 was found in groups III, IV, and V (64 %, 52%, and 47%). This suggests that the resin bracket interface was the source of the majority of the bracket failures. About 70% of light-cured adhesive failures, according to Jou et al.[20] occurred at the adhesive–bracket interface. The inability of the curing light to reach the adhesive beneath the bracket mesh is most likely due to insufficient polymerization of the resin beneath the bracket's metal base.

Scanning electron microscope analysis done on the representative tooth of each group at a magnification of ×3000 showed varying amount of adhesive remnants on the tooth surface. This confers with the mean ARI obtained in these groups. The higher the SBS, the greater the ARI score and deeper the resin tag penetration. In this study, Transbond XT with primer pre-curing showed the highest SBS and Orthofix with primer co-curing showed the lowest SBS. The SEM findings can be related to the values of the SBS and ARI in the study conducted by Sharma et al.[21] Nandhra et al.[2] in their study confirmed that the primary purpose of primer

Table 4: Tukey's HSD *post-hoc* test (pairwise comparison)

			95% of confidence interval		
(I)	*(J)*	*Mean difference (I – J)*	*Lower*	*Upper*	*p-value*
Group I	Group II	–3.94	7.3080	–0.5720	0.012*
	Group III	–8.89	–12.2580	–5.5220	0.0001*
	Group IV	–12.99	–16.3580	–9.6220	0.0001*
	Group V	–0.37	–3.7380	2.9980	0.99
	Group VI	–1.01	–4.3680	2.3680	0.95
Group II	Group III	–4.95	–8.3180	–1.5820	0.0006*
	Group IV	–9.05	–12.4180	–5.6820	0.0001*
	Group V	3.57	0.2020	6.9380	0.031*
	Group VI	2.94	–0.4280	6.3080	0.132
Group III	Group IV	–4.10	–7.4680	–0.7320	0.007*
	Group V	8.52	5.1520	11.8880	0.0001*
	Group VI	7.89	4.5220	11.2580	0.0001*
Group IV	Group V	12.62	9.2520	15.9880	0.0001*
	Group VI	11.99	8.6220	15.3580	0.0001*
Group V	Group VI	–0.63	–3.9980	2.7380	0.99

*$p < 0.05$ is statistically significant (Tukey's *post-hoc* test)

Table 5: Distribution of ARI scoring of the testing groups

Scores	*Group I*	*Group II*	*Group III*	*Group IV*	*Group V*	*Group VI*	*Total n*
Score 0 *n* (%)	0	0	6 (35.3)	4 (23.6)	3 (17.6)	2 (11.8)	17
Score 1 *n* (%)	3 (17.6)	5 (29.4)	11 (64.7)	9 (52.9)	8 (47.1)	6 (35.3)	17
Score 2 *n* (%)	10 (58.8)	2 (11.8)	0	3 (17.6)	6 (35.3)	6 (35.3)	17
Score 3 *n* (%)	4 (23.6)	10 (58.8)	0	1 (5.9)	0	3 (17.6)	17

ARI scores: (0) indicates no adhesive on enamel, (1) indicates <50% of adhesive left on enamel, (2) indicates >50% of adhesive left on enamel, and (3) indicates 100% of adhesive left on enamel

is enamel surface penetration to improve the effectiveness of the final bond. Because the enamel surface was more influenced by the conditioner, greater bond strength and more adhesive remnants were detected, as in the Transbond XT group.

One of the major drawbacks of this study is that, because it was conducted *in vitro*, it was unable to reproduce the oral environment. Biodegradation of the adhesive compound in the oral environment, according to Matasa,[22] can contribute to the breakdown of the bracket-to-tooth bond. Masticatory forces, varied patient participation, and orthodontic mechanotherapy during the time period of comprehensive fixed orthodontic therapy are some of the additional elements that contribute to a decrease in the SBS in the oral environment.

Conclusion

It is reasonable to draw the conclusion, within the constraints of this in vitro study, that primer pre-curing increased the SBS of orthodontic brackets adhered to a tooth surface. Co-curing of the primer with adhesive resulted in a lower bond strength. In all groups, the ARI data revealed a varied pattern of resin–bracket failure. There was statistically significant difference between the groups, with most of them showing bond failure at the resin–bracket interface. This is favorable to avoid enamel fractures and SEM analysis confirmed the ARI findings.

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