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Evaluation of shear bond strength and adhesive remnant index of four adhesive resin systems using metallic and ceramic brackets

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Abstract: Introduction: *Bracket debonding from the tooth surface is a common problem in fixed orthodontics. The present study was done to assess the bond strength and failure sites with metallic and ceramic brackets.*
Materials and Methods:*160 human maxillary premolars were assigned to 2 groups (metallic and ceramic) and were further subdivided into 4 Subgroups according to the generations of adhesive system used i.e. Transbond XT light cure adhesive (3M UNITEK), Heliosit Orthodontic (IVOCLAR VIVADENT), Transbond self-etching primer (3M UNITEK), Optibond All-In-One adhesive (KERR DENTAL). Bracket bonding was done according to the respective adhesive manufacturer's instructions and all samples were stored in distilled water at 37℃ for 24 hrs and shearing force was applied to the bracket-tooth interface using Universal Testing Machine. Bonding failure site optically examined using a stereomicroscope and scoring was done using the adhesive remnant index (ARI).*
Result*s:Mean shear bond strength values (in MPa) for metallic brackets were higher for Transbond XT Subgroup followed by Optibond subgroup, Heliosit Subgroup and Transbond self-etch primer Subgroup. Mean shear bond strength values for ceramic brackets were higher for Transbond XT Subgroup followed by Transbond Self etch primer, Optibond Subgroup and Heliosit Subgroup.Bond strength differences between groups 1 and 2 were not significant. Significant difference was found in ARI between both the groups.*
Conclusion: *The bond strengths of metallic brackets were higher than ceramic ones. A positive correlation found between changes in shearing bond strength and ARI.*
Key words: *Acid etching, orthodontic brackets, shearing bond strength.*

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I. Introduction

Enamel bonding for orthodontic application was introduced in 1965 and is considered a significant milestone in orthodontic treatment. The transformation from banding complete arches to direct bonding has decreased the chair side time, demineralization and band spaces at the end of treatment for the clinician. Also, bonding of tooth surface is esthetically more superior as compared to banding. Buonocore (1955) found an increase in the adhesion of acrylic materials used at that time when the enamel surface had been treated with 85% phosphoric acid solution for 30 seconds. The acid etching technique was introduced to bond dental restorations to the tooth structure was considered as a breakthrough point in the history of orthodontic bonding.

Shear bond strengths generally range from 20 to 25 MPa when resin-based composite is bonded to enamel etched with 37% phosphoric acid. A bracket must resist a displacement force of at least 6–8 MPa for clinical success.To increase esthetics, ceramic brackets were introduced as an alternative to traditional stainless steel brackets in 1987.An orthodontic bracket must be able to deliver an optimal orthodontic force, must be able to withstand the masticatory loads and should be easily removed at the end of the treatment with the minimal damage to the tooth surface. Conventional orthodontic adhesive systems (Fourth Generation) consist of 3 agents: enamel conditioner (acid), primer solution (unfilled resin), and adhesive (resin composite).

Advances in adhesive technology have led orthodontists to introduce new adhesives, composite resins, and bonding techniques into clinical practice. Self-adhesive systems (Fifth Generation) contain primer and bonding agent combined in a single step. The reduction in the number of steps for bonding procedures decreases harm to the enamel surface and minimizes bond failures during orthodontic treatment. In addition, the use of acidic primers decreases the amount of residual adhesive on the enamel surface after debonding.

Recently, a 1-step adhesive system has been introduced and used in restorative dentistry. It combines etchant, primer, and adhesive resin in 1 paste. It has several advantages, including a decrease in the possibility of contamination during bonding procedures and saves chair time. Most self-etching primers (Sixth Generation) are 2-component systems, with the etching and priming procedures combined in the first step that simplify the bonding procedure, reduce chair side time and avoid the side-effects of acid etch technique. New single-component self-etching and self-adhesive resin systems (Seventh Generation) have been introduced. These dualcure systems can be used without surface preparation and these products combine etchant, primer, and adhesive resin in a single paste.

The purpose of this study is the evaluation of shear bond strength and adhesive remnant index of four commonly used adhesive resins systems used with metallic and ceramic brackets, to compare and find any difference between newer generation of adhesive system and convention adhesive resin system and to comparatively assess the amount of each bonding agent remaining on the enamel after debonding by means of adhesive remnant indexing.

These adhesive systems include:

1. Generation 4: Conventional systems as three component system using etchant, primer and adhesives separately.
2. Generation 5: Total etch system contains single component - primer and adhesive in 1 bottle
3. Generation 6: Self-adhesive systems containing etchant and primer in same compartment.
4. Generation 7: All – in–one adhesives that contains etchant, primer and adhesive in one compartment.

II. Material And Methods:

THE TEETH

160 extracted human premolars were collected. Majority of the teeth used in the study were extracted therapeutically for orthodontic treatment. The teeth were stored in a bottle containing distilled water, immediately after extraction and examined macroscopically for following inclusion criteria:maxillary first premolars with intact buccal surface,sex, race and malocclusion differences were ignored. Exclusion criteria included premolars with carious / abraded / eroded buccal surfaces, fluorosed / hypoplastic premolar teeth, fractured/cracked teeth due to pressure of extraction forceps.

DISTRIBUTION OF SAMPLE:

The samples were randomly divided into 2 groups of 80 teeth each that would receive metallic and ceramic brackets respectively. Each group were further subdivided into 4 subgroups of 20 teeth each on the basis of generations of adhesive systems as following: Subgroup 1 (Transbond XT group); Transbond XT light cure adhesive (3M UNITEK), Subgroup 2 (Heliosit group); Heliosit Orthodontic (IVOCLAR VIVADENT), Subgroup 3 (Self etch primer group); Transbond self-etching primer (3M UNITEK), Subgroup 4 (Optibond group); Optibond All-In One adhesive (KERR DENTAL).

MOUNTING OF TEETH

The teeth were mounted with their roots embedded in the dental stone (Kalstone, KALABHAI) bases such that their facial surfaces were perpendicular to the bottom of base which was visually inspected. The blocks with the teeth mounted were later randomly divided in 8 batches having 20 blocks each and stored in distilled water at room temperature before subjecting them to shear bond strength test.

THE BRACKETS

80 Maxillary first premolar metallic brackets with 7° torque, 0° tip and MBT 0.022-inch archwire slot. The bracket base area and mesh size provided by the manufacturer was 9.818mm^2 and 80 mesh at 45° (Sapphire-

MODERN ORTHODONTICS).

80 Maxillary first premolar ceramic brackets with 7° torque, 0° tip and MBT 0.022-inch archwire slot. The bracket base area provided by the manufacturer was 11.085mm^2 (D'art- MODERN ORTHODONTICS).

PROPHYLAXIS

The teeth were cleaned and pumiced by using a rubber cup with prophylactic paste (PROPHYPASTE, PrevestDentpro) in a slow handpiece for 15 seconds. These were then thoroughly washed with distilled water and air-dried with oil and moisture-free air source till desiccation.

BONDING

In Subgroup 1 (Transbond XT group; n=20) the bonding was done using Transbond XT light cure adhesive. Unitek™ Etching Gel was applied to teeth on the middle third of the buccal surface surfaces for 30 seconds, rinsed with water and air dried thoroughly. Thin uniform coat of primer was applied on each tooth surface to be bonded and cured for 10 seconds. A small amount of Transbond XT adhesive paste was applied with a syringe onto bracket base. The brackets were lightly placed onto teeth surfaces and adjusted at the centre of the buccal surface of the teeth and pressed firmly to seat the bracket and was light cured for 20 seconds according to manufacturer's instruction.

In Subgroup 2 (Heliosit group; n=20), the bonding was done using Heliosit Orthodontic (IVOCLAR VIVADENT) that contains primer and adhesive in 1 syringe. The teeth were conditioned with 37% Ortho-phosphoric acid (Unitek™ Etching Gel) for 15 seconds, washed with water and dried to frosty white appearance. The highly translucent single-component Heliosit Orthodontic (IvoclarVivadent AG) bonding material was applied to the under surface of the brackets. Brackets were then bonded and light-cured as in Subgroup 1.

In Subgroup 3 (Self etch primer group; n=20), the bonding was done using Transbond self-etching primer (3M UNITEK). The teeth were conditioned with a self-etching primer on the enamel surface for at least 3 seconds. After that Transbond adhesive was applied to the metallic bracket, the bracket was bonded at the centre of the buccal surfaces of the teeth and was light cured for a total of 20 seconds according to the manufacturer instruction.

In Subgroup 4 (Optibond group; n= 20), the bonding was done using Optibond All–In-One (KERR DENTAL) adhesive. The adhesive was applied for 20 seconds on the tooth surface and air dried for at least 5 seconds, a second layer of adhesive was applied and air dried and light cured for 10 seconds. Dyad-flow composite was applied on the bracket base and then placed at the centre of the buccal surfaces of the teeth and pressed firmly to seat the bracket to the final position and light cured according to manufacturer instruction.
Same procedure was repeated for the ceramic brackets and light was directed through the bracket . After bonding, all samples were stored in distilled water at 37℃ for 24 hrs.

The shear bond strength was measured using Universal Testing Machine (WDW 10KN Banbros, Taiwan) at a crosshead speed of 0.5mm/min. A computer connected to the universal testing machine recorded the load required to debond the bracket in Newtons (N) and converted it into stress per unit area (mega newtons per square meter) by dividing the force by the unit area of the base of the bracket megapascals ($MPa=N/mm^2$).

Adhesive Remnant Index:

After debonding, the enamel surfaces of the teeth were examined under a stereomicroscope at 10x magnification. Any adhesive remaining after bracket removal was assessed with the Adhesive Remnant Index (Artun and Bergland).[13] The modified ARI scale (Bordeaux et al)[14] has a range between five and one,
Type 1: Failure at the adhesive–bracket base interface.
Type 2: Combination failure at the adhesive–bracket base interface and the enamel -adhesive interface.
Type 3: Failure at the enamel-adhesive interface.
Type 4: Failure of the bracket itself.
Type 5: Failure of the enamel itself.
The ARI score was assessed by the same operator. After the completion of the testing all the data obtained was tabulated and subjected to statistical analysis.

III. Result:

SHEARING BOND STRENGTHS OF THE GROUPS

Mean shear bond strength value for metallic bracket were 29.55 ± 9.6MPa, 23.10 ± 9.02MPa, 22.91± 11.40MPa and 23.15 ±7.78MPa with a range of 15.36MPa to 46.32MPa, 9.6MPa to 36.89MPa, 14.08MPa to 59.14MPa and 15.05MPa to 39.60MPa respectively for Transbond XT Subgroup, Heliosit Subgroup, Transbond self-etch primer Subgroup and Optibond Subgroup and mean shear bond strength value for Ceramic group were 27.63 ±12.21MPa, 23.77 ± 15.85MPa, 19.31 ± 7.61MPa and 16.22 ± 4.68MPa with a range of 13.01MPa to 55.07MPa, 8.99MPa to 27.70 MPa, 5.90MPa to 58.22 MPa and 39.78MPa to 10.59 MPa respectively for Transbond XT Subgroup, Transbond Self etch primer, Optibond Subgroup, Heliosit Subgroup as shown in Table 1, Graph 1.

Adhesive Remnant Index

Metallic Group

In Transbond XT Subgroup: 75% samples showed type 1 failure, 15% samples showed type 2 failure whereas 10% sample showed type 3 failure each. Heliosit Subgroup reported 35% samples in type 2 failure followed by 65% samples in type 3 failure. In Transbond self-etch primer Subgroup: 70 % samples showed type 3 failure, 25% in type 2 whereas only 5% showed type 5 failure and in Optibond Subgroup: 40% samples showed type 2 failure, 60% in type 3 failure as shown in Table 2.

Enamel failure was observed in 1 sample i.eTransbondSelf etch primer Subgroup. The Chi-Square test was applied to determine significant association in the ARI scores between different test groups. The type of failure between the test groups was found to be significant with a p value equal to 0.05 as shown in Table 3.

CERAMIC GROUP

In Transbond XT Subgroup: 40% samples reported type 1 failure, 20% samples showed type 2 failure, whereas 40% sample showed type 3 failure each. In Heliosit Subgroup: 10% samples reported type 1 failure followed by 25% samples in type 2 failure and 65% samples in type 3 failure. In Transbond self-etch primer Subgroup: 10 % samples showed type 1 failure, 25% in type 2, whereas 65% showed type 3 failure and in Optibond Subgroup: 50% samples showed type 2 failure, 50% in type 3 failure as shown in Table 4.

The Chi-Square test was applied to determine significant association in the ARI scores between different test groups. The type of failure between the test groups was found to be significant with a p value equal to 0.05 as shown in Table 5.

Table: 1 Mean Shear bond strength of various adhesive systems in metallic and ceramic groups:

	Groups	No.	Mean	SD	Min.	Max.	Mean difference	'p' value
Transbond XT	**Metallic** **Ceramic**	20 20	29.55 27.63	9.66 12.21	15.36 13.01	46.32 55.07	2.92	0.069
Heliosit	**Metallic** **Ceramic**	20 20	23.10 16.22	9.02 4.68	9.61 8.99	36.89 27.70	6.78	0.809
Transbond self-etch	**Metallic** **Ceramic**	20 20	22.91 23.77	11.40 15.85	14.08 5.90	59.14 58.22	-0.68	0.545
Optibond All in one	**Metallic** **Ceramic**	20 20	23.15 19.31	7.78 7.61	15.05 10.59	39.60 39.78	6.84	0.839

*The mean difference is significant at the *< 0.05 Level,**<0.01 Level***<0.0001 Level

Ari Scores For Different Test Groups

Table 2: ARI Scores for composites (With metallic bracket).

Type of failure	Transbond XT	Heliosit	Transbond self-etch	Optibond All- in -One	Total no. of samples
1	15	0	0	0	15
2	3	7	5	8	23
3	2	13	14	12	41
4	0	0	0	0	0
5	0	0	1	0	1
Total	20	20	20	20	80

Table 3: Chi Square Test for determination of level of significance among various adhesive systems in metallic bracket

Chi-Square Tests			
	Value	Df	P value
Pearson Chi-Square	**20**	**1**	**.05***
Likelihood Ratio	18	2	0.449
N of Valid Cases	20	2	

The mean difference is significant at the *< 0.05 Level,** <0.01 Level***<0.0001 Level.

Table 4: ARI Scores for composites (With ceramic bracket).

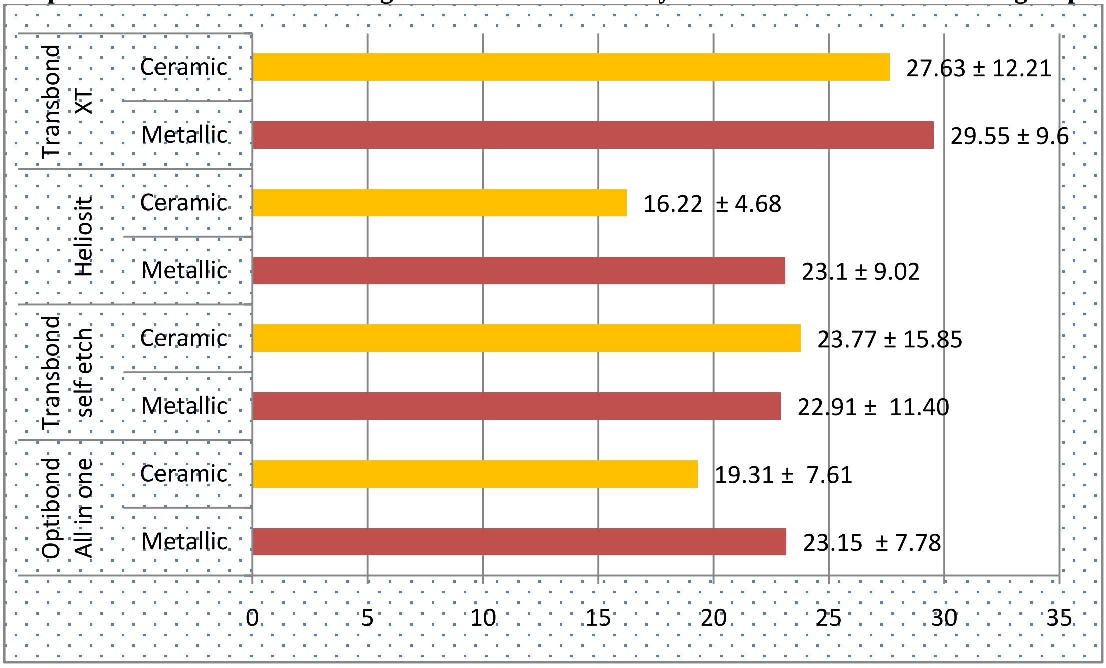
Type of failure	Transbond XT	Heliosit	Transbond self-etch	Optibond All- in -One	Total no. of samples
1	8	2	2	0	19
2	4	5	5	10	23
3	8	13	13	10	38
4	0	0	0	0	0
5	0	0	0	0	0
Total	20	20	20	20	80

Table 5: Chi Square Test for determination of level of significance among various adhesive systems in ceramic bracket

Chi-Square Tests			
	Value	Df	P value
Pearson Chi-Square	**20**	**1**	**0.05***
Likelihood Ratio	18	2	0.819
N of Valid Cases	20	2	

The mean difference is significant at the *< 0.05 Level,** <0.01 Level***<0.0001 Level.

Graph 1: Mean Shear bond strength of various adhesive systems in metallic and ceramic groups:



IV. Discussion:

The direct bonding of orthodontic brackets has revolutionized and enhanced the clinical practice of orthodontics. This procedure was immediately and widely accepted by all orthodontists due to its simplicity and reduced chair time. Brackets in the oral cavity are subjected to variety of forces. Their shear bond strength is influenced by various factors like surface area, conditioning procedures, types of adhesives used, bracket base design, the treatment of bracket base and protocol followed during bonding. Ideally, an orthodontic bracket must be able to deliver an optimal orthodontic force, must be able to withstand the masticatory loads and should be easily removable at the end of the treatment with the minimal damage to the tooth surface[15].

The result of the present study showed that Transbond XT Subgroup (metallic group) had highest shear bond strength; followed by Optibond Subgroup, Heliosit Subgroup, and least for Transbond self-etch primer Subgroup as shown in Table 1, Graph 1. These results were similar to the study conducted by Douglas Rixet al[1] among 3 different orthodontic adhesives and reported that Transbond XT Subgroup had significantly greater shear bond strength (20.19±4.71MPa). However, in their study, Transbond XT showed lesser value of shear bond strength (20.19±4.71MPa) in comparison to Transbond XT Subgroup of the present study. The bond strength achieved in the present study for Heliosit orthodontic adhesive was higher than the ones achieved by Aasrumet al[2] (6.4 MPa with a range of 42.5-121.7MPa) and Bradburn and Pender[3] (7.22±2.11MPa), Joseph and Rossouw[4] (17.80±3.54MPa) and Owais Khalid et al[6] (10.54±1.86MPa).

In the present study, ceramic brackets bonded with the Transbond XT showed the highest bond strength followed by Transbond Self etch primer Subgroup, Optibond Subgroup and least for Heliosit Subgroup as shown in Table 1, Graph 1. These results were similar to the study conducted by TancanUysal et al[16], who evaluated the bond strengths of ceramic bracket with Transbond XT was 36.7±11.8MPa and with self-etching adhesive was 26.6±8.9MPa.

The ARI scores in Group 1 (Metallic brackets) were predominantly 1-3 (score) among all the subgroups. Transbond XT Subgroup had 75% type 1 failure (ARI Score) that could be due to the fact that enamel conditioning by 37% phosphoric acid was used that results in greater depth of penetration of the resin as compared to Transbond Self etch primer Subgroup which had 70% type 3 failure. Hence, among all the metal groups, the failure point was predominantly in the enamel/adhesive interface except for Transbond XT due to its greater penetrability into enamel surface.

However, in ceramic brackets, the failure mainly occurred at enamel/adhesive interface (type 3 failure) and within adhesive (type 2 failure) whereas in Transbond XT Subgroup, a combination of ceramic bracket and higher bond strength of adhesive (due to acid etching technique and low viscosity intermediate resin) resulted in mixed failure i.e at enamel adhesive interface (40%), adhesive bracket interface (40%).

In the present in-vitro study, all the adhesive resin systems achieved bond strength more than the optimal bond strength i.e. 6-8 MPa as suggested by Reynolds[17] and as such no damage to the enamel surface was experienced except in metallic bracket bonded with Transbond Self etch primer where minimal amount of enamel (5%) was chipped off as shown in Table 2. Therefore, all the four generations of composite resin namely; Transbond XT (4th Generation), Heliosit orthodontic (5th Generation), Transbond self-etch (6th Generation), Optibond All in one (7th Generation) can be recommended as a clinically effective bondable composite for metallic and ceramic bracket in orthodontic patients.

V. Conclusion:

Within the limitations of this in vitro study, the following conclusions were drawn,

1. All the four adhesive systems can be used in orthodontics as they exhibit higher values than the minimum orthodontic bracket bond strength range of 6 – 8 MPa.[17]
2. Metal brackets bonded with Transbond XT yielded the highest shear bond strength among all groups.
3. Ceramic brackets bonded with Heliosit composite reported the lowest shear bond strength among all the adhesive systems used in the study.
4. All the samples bonded with metal brackets yielded shear bond strength higher than ceramic brackets except Transbond Self etch where shear bond strength of ceramic bracket is greater than metallic that is statistically nonsignificant.

Thus, the present study proves that all the four adhesive systems namely; Transbond XT (4^{th} Generation), Heliosit orthodontic (5^{th} Generation), Transbond self-etch (6^{th} Generation), Optibond All in one (7^{th} Generation) can be used with metallic and ceramic brackets.

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