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RESEARCH ARTICLE

COMPARATIVE EVALUATION OF SHEAR BOND STRENGTH AND SURFACE ENAMEL LOSS OF THREE ORTHODONTIC ADHESIVES BONDED TO METAL BRACKETS

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ABSTRACT

Background and Objectives*:* Attachments with sufficient bond strengths and a low failure rate are required for a fixed orthodontic appliance to be successful. For bonding brackets to enamel surfaces, a variety of adhesives have been employed and optimal color and shade match of composite resins and teeth, make identification of adhesive–tooth interface difficult and complete removal of adhesive remnants may not be easily achieved. Color-change light-cured composites were recently introduced to the orthodontic market to enhance differentiation of adhesive and enamel. The objective of this study is to compare the shear bond strength, adhesive remnant index and enamel loss while debonding between two color changing adhesive with a conventional orthodontic adhesive. ***Methods****:* 120 human maxillary teeth freshly extracted was collected and stored. Then specimen was randomly divided into three groups and bonded accordingly. Among 40 samples prepared in each group, 20 samples were taken for shear bond test. Remaining 20 samples was debonded manually by using a debonding plier. The debonded tooth surfaces of 20 samples were examined under stereomicroscope of 10x magnification to assess residual adhesive on tooth surface and site of bond failure using Adhesive remnant index. The debonded bracket base of 20 samples was examined under Scanning Electron Microscope and Energy dispersive X ray spectroscopy to detect calcium and phosphorus. ***Result and Discussion****:* There was no statistically significant difference between the shear bond strength of Grengloo and Transbond Plus color changing adhesives. Energy dispersive X ray spectroscopy analysis showed a significantly high amount of elemental Calcium (Ca) and Phosphorous (P) on Transbond Plus. There were significant differences found in enamel loss by color changing adhesives. Significant result was found between shear bond strength of color changing adhesive and Transbond XT conventional adhesive. ***Conclusion:*** Metal brackets bonded with color changing adhesives have shown good shear bond strength with minimal enamel loss with Grengloo. Transbond plus showed significantly high amount of elemental Calcium (Ca) and Phosphorous (P).

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INTRODUCTION

Orthodontics is a constantly evolving specialty with research for improvements in its techniques and materials that benefit both the patients as well as the clinicians. For the direct attachment of orthodontic brackets to tooth surface with resin adhesive, Newman[1] modified the acid-etch process of Buonocore[2] in 1965 for orthodontics. The direct bonding procedure is better for the patient and the practitioner in terms of treatment as well as clinical time.[3] Two main concerns regarding the bracket bonding despite of its advantages are presence of adhesive remnants on the tooth surface which compromises the enamel integrity and recovery of enamel surface back to its baseline state after bracket removal[4, 5].

Another problem with regard to the use of light-cured and self-cured conventional composites for bracket bonding is lack of color contrast with the enamel, which may result in accumulation of resin remnants on the enamel surface after bracket debonding and polishing. Color-change light-cured composites were recently introduced to the orthodontic market to enhance differentiation of adhesive and enamel. Due to their different colors and contrasts, they can be easily detected on the tooth enamel during bonding and debonding procedures. Furthermore, after bracket bonding, excess resin can be easily removed, which is an advantage. [6, 7, 8] Appliance and bracket removal does cause some scarring to the tooth surface.[9] An ideal bonding material should have optimal bond strength and minimal enamel loss after debonding.[10] The bond strength of the orthodontic brackets must be able to withstand not only the forces applied during the orthodontic treatment but the masticatory forces as well. Adequate bond strength of a material that is clinically acceptable for performing orthodontic treatment is 5.9-7.8MPa. To reduce the extent of enamel loss on debonding the maximum bond strength should be less than the cohesive strength of enamel, which is approximately 14MPa.[11]

Accordingly there is always a search for an orthodontic adhesive material which has better shear bond strength but with minimal enamel loss during debonding. An important factor in the selection of orthodontic bonding material is the assessment of the adhesive remnant on tooth surface after debonding.[12] The amount of adhesive remaining on the enamel surface and site of bond failure was assessed by Artun and Bergland[13]using Adhesive Remnant Index. The most favorable failure site for safe debonding, is the bracket-adhesive interface since there is less chance of enamel fracture and it is considered ideal if the adhesive remains on the tooth surface after debonding.[14] Energy dispersive X-ray spectroscopy, when used in conjunction with a high-resolution scanning electron microscope, enables the quantitative analysis of samples by measuring the quantity of Calcium and Phosphorous bound to the debonded bracket base through the emission of distinctive x-rays. Grengloo is a color-change adhesive, which is green in color at temperatures lower than the body temperature. This enhances removal of excess composite during bracket bonding.[15] Transbond Plus is a color change orthodontic bonding adhesive manufactured by 3M Unitek. It incorporates a pink dye that becomes photobleached when it is exposed to light, both ambient and curing.[16] Studies on the shear bond strength and debonding characteristics of Grengloo and Transbond Plus are scarce and only limited data available to assess the bonding and debonding characteristics of these CCAs to compare with proven clinically acceptable material like Transbond XT. In this study, Grengloo (Ormco Corp.), Transbond plus (3M Unitek), and Transbond XT (3M Unitek) were compared for shear bond strength using a universal testing machine, adhesive remnant index (ARI) using a stereomicroscope at a 10x magnification, and enamel loss during debonding using energy dispersive x-ray spectroscopy

MATERIALS AND METHODS

An in-vitro extensive study was planned to assess and compare the bonding and debonding characteristics of three different orthodontic adhesives.

Bonding Materials Used

Composite Adhesive: Grengloo (Ormco Corporation, Orange, California), Transbond Plus (3M Unitek, Monrovia, California), Transbond XT (3 M Unitek, Monrovia, California).

Primer: Transbond XT (3 M Unitek primer, Monrovia, California), Orthosolo Primer (Ormco Corporation, Orange, California).

Etchant: 37 % Phosphoric acid solution (Scotchbond 3 M Unitek, Monrovia, California).

Brackets Used: Stainless steel brackets- 120 Maxillary premolar brackets 0.022" slot MBT series (LEONE, Italy).

Teeth Samples: 120 human maxillary premolars extracted for therapeutic purpose were used as the samples.

Inclusion criteria

- Teeth with intact crowns, free from attrition and hypo-plastic areas, cracks, gross irregularities, decays and fractures.

Exclusion Criteria

- Teeth with caries, enamel cracks, gross irregularities, decays and fractures.
- Teeth with history of orthodontic bonding
- Teeth with composite restorations
- Teeth treated with fluoride

Storage: The samples were stored in a 0.1% (wt/vol) aqueous solution of thymol at room temperature for seven days to prevent bacterial contamination and dehydration. Then the teeth were subsequently placed in distilled water at 4ºC.

Mounting: The roots were completely embedded into the color coded acrylic blocks up to cementoenamel junction. The dimension of the acrylic blocks were 25 x 10 x 10mm.

Classification of samples into three groups: Group 1Gren-gloo (with Ortho Solo primer) 40nos Blue Group 2Transbond Plus (with Transbond XT primer) 40nos Black Group 3Transbond XT (with Transbond XT primer) 40nos Red

Bonding Procedure

Prophylaxis: Each tooth's buccal surface was scrubbed with pumice using a rubber cup micromotor hand piece for 10 seconds, followed by rinsing and drying with oil-free compressed air.

Etching: The enamel surface on the buccal aspect of teeth was etched using 37 percent phosphoric acid (Scotchbond – 3M ESPE) for 15 seconds, rinsed with water for 20 seconds and completely air dried for 30 seconds with compressed air.

Priming: A thin, uniform film of Transbond XT primer was applied to group 1 and group 2 and Ortho Solo primer was applied to group 3.

Applying bonding adhesive:

Group 1: Grengloo with Ortho Solo primer was placed onto the metallic bracket base.

Group 2: Transbond Plus with Transbond XT primer was placed onto the metallic bracket base.

Group 3: Transbond XT with Transbond XT primer was placed onto the metallic bracket base.

And the bracket was firmly pressed on the prepared enamel; the excess adhesive was then removed with an explorer.

Curing: Brackets were light cured for 10 seconds on occlusally and gingivally for a total of 20 seconds per tooth using Bluephase N LED light curing unit. The teeth were then stored for 24 hours in distilled water at 37ºC before debonding.

The study was conducted in three parts: Each group consisted of 40 samples. 20 samples were taken for shear bond test.20 samples were manually debonded and taken for Energy Dispersive X ray Spectroscopy (EDAX or EDX) and ARI index.

Shear Bond Testing Procedure: The 20 samples from each group were tested for shear bond strength using Universal testing machine Tinius Olsen from Polymer Science Department (CUSAT) .The acrylic block was mounted on a universal joint to ensure that the

applied force was parallel to the tooth surface. The force was applied with a beveled flattened steel rod at the bracket-tooth interface at a crosshead speed of 0.5 mm per minute in an occlusogingival direction. The force values (in Newton) recorded at the point of failure was converted to shear stress by dividing by the bracket surface area (mm^2) and was reported in megapascals (N/mm2) for all 60 samples.

Debonding: The remaining 20 samples from each group were debonded manually by using the debonding plier 001-346E Direct Bond Bracket Remover (SKODI).

Adhesive Remnant Index (ARI): 20 samples from each group were debonded manually by using normal bracket removing pliers. The debonded tooth surface were examined under optical stereomicroscope of 10x magnification from Polymer Science Department, CUSAT to assess the residual adhesive on the tooth surface and site of bond failure using Adhesive remnant index (ARI), done by a single observer. Analysis of residual adhesive on the tooth surface was done according to Artun and Bergland– ARI score by visualizing in the microscope and the scores were made.

The criteria for scoring were as follows:

0 = No adhesive on the tooth
1= Less than half of the adhesive on the tooth
2= More than half of the adhesive on the tooth
3= All the adhesive on the tooth, with a distinct impression of the bracket mesh.

Energy Dispersive X Ray Spectroscopy: The debonded bracket bases were examined under Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectrometry (EDAX-analysis) JOEL JSM6390, from Sophisticated Testing and Instrumentation Centre (STIC), CUSAT to detect calcium (Ca) and phosphorus (P).The debonded bracket base used in the study were mounted on aluminium stubs and obtained a vacuum of 20 Pascal. Bracket base were sputter coated with gold for 30 seconds and were removed and placed in scanning electron microscope, areas of elemental analysis were selected and analyzed with EDAX at accelerating voltage of 20kv. Bracket bases were examined by 30x and 500x used to verify the amount of adhesive remnant on the bracket base.30x magnification to determine the mode of failure and 500x magnification for detecting enamel fragments.SEM analysis provide only qualitative evaluation so the bracket bases were examined through Energy Dispersive Spectroscopy to determine quantitative analysis of enamel loss. The EDAX uses the X-rays to identify traces of elements on the surface of the scanned specimens.

RESULTS

Data was analyzed using the statistical package SPSS 26.0 (SPSS Inc., Chicago, IL) and level of significance was set at $p<0.05$. Descriptive statistics was performed to assess the mean and standard deviation of the respective groups.

Table 1. Analysis of shear bond strength

	GROUP	MEAN	SD
SHEAR BOND STRENGTH	GRENGLOO (A)	14.76	1.06
	TRANSBOND PLUS(B)	13.97	1.15
	TRANSBOND XT (C)	12.77	1.13
P VALUE (ONE WAY ANOVA TEST)		0.0001*	
POSTHOC TEST	A vs B	0.07	
	A vs C	0.0001*	
	B vs C	0.003*	

Normality of the data was assessed using Shapiro Wilkinson test. Since the data was following normal distribution and parametric test were used for the data analysis. Inferential statistics to find out the difference was done One way ANOVA test followed by Tukey's HSD test to check the difference between the pair groups. CHI SQUARE test was used to detect the difference in proportion.

TABLE 2. Analysis of SEM EDAX VALUE (CALCIUM & PHOSPHOROUS)

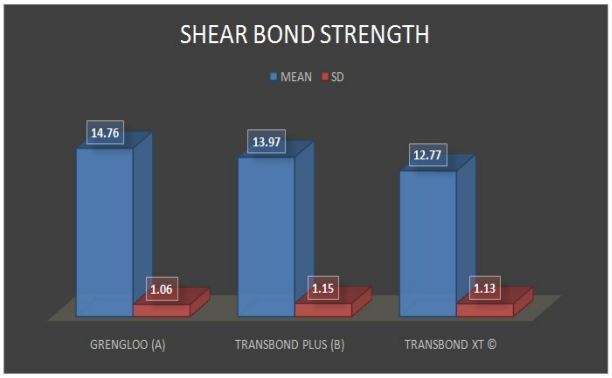
	GROUP	CALCIUM	PHOSPHOROUS
RELEASE	GRENGLOO (A)	3.69±0.33	2.18±0.41
	TRANSBOND PLUS (B)	4.37±0.31	2.24±0.22
	TRANSBOND XT (C)	1.54±0.18	0.67±0.32
P VALUE (ONE WAY ANOVA TEST)		0.0001*	0.0001*
POSTHOC TEST	A vs B	0.0001*	0.83
	A vs C	0.0001*	0.0001*
	B vs C	0.0001*	0.0001*

*P <0.05 is statistically significant

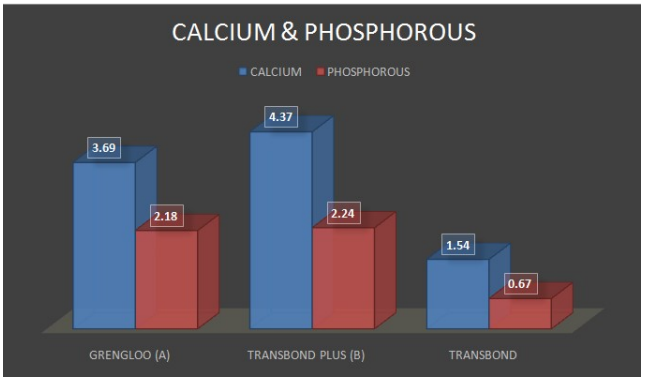
Table 3. Analysis of ARI INDEX

SCORE	GROUP 1	GROUP 2	GROUP 3
0	1 (5%)	0	0
1	6 (30%)	6 (30%)	4 (20%)
2	6 (30%)	8 (40%)	6 (30%)
3	7(35%)	6 (30%)	10 (50%)
P VALUE (CHI SQUARE TEST)	0.002*		

*P <0.05 is statistically significant



Graph 1. Comparison of Shear Bond Strength



Graph 2. Comparison of Enamel Loss in form of Calcium and Phosphorous

Graph 3. Comparison of ARI

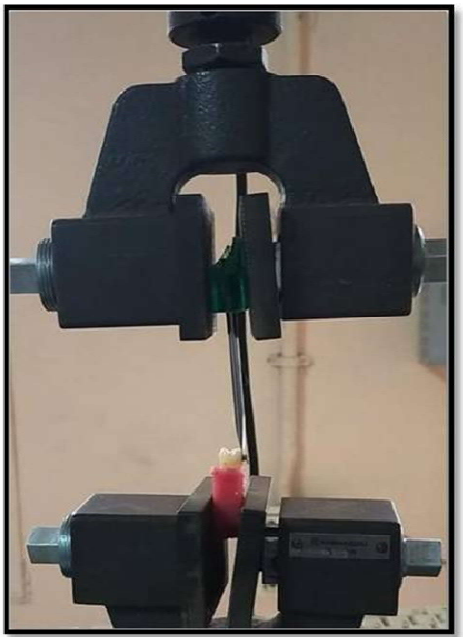


Figure 1. Universal Testing Machine

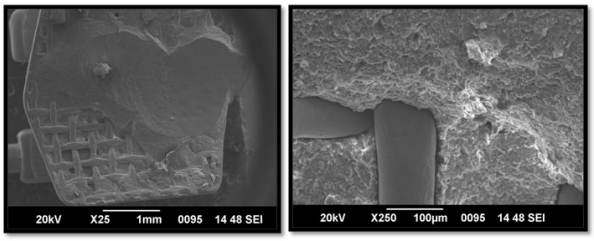


Figure 2(a) (b) SEM images of bracket base after debonding of Group 1

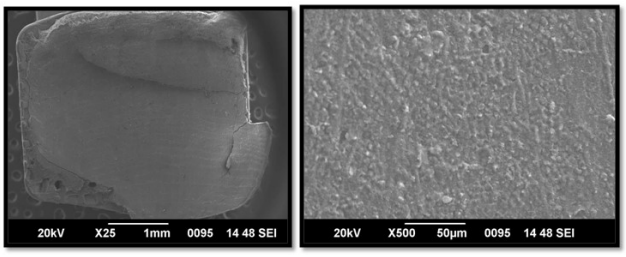


Figure 3. (a) (b) SEM images of bracket base after debonding of Group 2

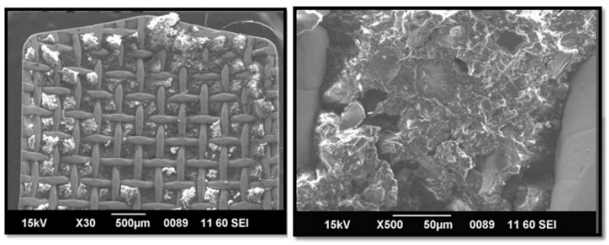


Figure 4 (a) (b) SEM images of bracket base after debonding of Group 3

Two tailed One way Anova test reported significant difference regarding the shear bond strength ($p<0.05$). Post hoc test analysis was done to analyze the pair group significance. Significant difference was observed between Grengloo Vs Transbond XT (14.76 Vs 12.77) and Transbond Plus Vs Transbond XT (2.18 Vs 0.67). Grengloo Vs Transbond Plus (2.18 Vs 2.24) difference was found to be non significant) ($P>0.05$).

Two tailed One way Anova test reported significant difference regarding the Calcium & Phosphorous ($p<0.05$). Post hoc test analysis was done to analyze the pair group significance regarding calcium and phosphorous. Regarding calcium release significant difference was observed between Grengloo Vs Transbond XT (3.69 Vs 1.54), Transbond Plus Vs Transbond XT (4.37 Vs 1.54) Grengloo Vs Transbond Plus (3.69 vs 4.37). Regarding Phosphorous release significant difference was observed between Grengloo Vs Transbond XT (2.18 Vs 0.67) and Transbond Plus Vs Transbond XT (2.18 Vs 0.67). Grengloo Vs Transbond XT (2.18 vs 2.24) difference was found to be non significant.) ($P>0.05$). CHI SQUARE test analysis was done to check the difference between three groups regarding the ARI scores. The analysis reported statistically significant difference in ARI scores between the groups ($p<0.05$).

DISCUSSION

Color-change adhesives are a novel modality for bracket bonding. They were introduced to the market aiming to enhance removal of composite remnants after bracket debonding because of color contrast.[6, 7, 12] Composite remnants cause enamel decalcification and gingival inflammation and studies have reported composite remnants covering as much as 6.94 mm of the enamel surface after bracket debonding.[17,18] In orthodontic procedures, the debonding of brackets either by accident or by an orthodontist is a frequent event. The adhesion between orthodontic composite resins and the tooth enamel should be temporary, but it should last enough to withstand masticatory and orthodontic forces at the same time. Iatrogenic damage to enamel on debonding is inevitable, in scenarios where the tensile bond strength was above 14.5 MPa on debonding, enamel damage was reported. The calcium loss from the enamel surface can lead to dental erosion, which is a localized loss of dental hard tissues.[19]When selecting an adhesive for an orthodontic procedure, shear bond strength, the location of bond failure, the amount of enamel loss, cost, and chair time must all be considered. In the present study the properties of two color changing adhesives- Grengloo and Transbond Plus were compared with conventional light- cured orthodontic bonding adhesive- Transbond XT.

Grengloo is a two-way color change adhesive which polymerizes faster than other light-cured orthodontic bonding adhesives providing a higher percent of total bond strength at initial force loading. It is also designed with patented ingredient which increases impact resistance by 118 percent and has a chemical affinity for metal brackets which can ensure reliable bond strength. The green color contrast at lower temperatures during bonding facilitates accurate bracket placement and makes it easy to remove excess adhesive.[15] Transbond Plus is a color change orthodontic bonding adhesive which incorporates a pink dye that becomes photobleached when it is exposed to light, both ambient and curing. The intended benefit of the dye is to facilitate the removal of excess adhesive during bracket placement that will potentially cause the building of plaque.[16] The mean Shear bond strength of Grengloo (Group 1) and Transbond Plus (Group2) according to the current study were 14.75 MPa and 13.97 MPa respectively which was statistically not significant. Group 1 had higher SBS compared to Group 2 which is consistent with the results of Türkkahraman et al[12] who reported mean SBS of Grengloo as 19.2±3.3 MPa and they concluded that the SBS of Grengloo with metal bracket was significantly higher than Transbond Plus with metal bracket. The relatively higher bond strengths of Grengloo may be due to the sealant, Ortho Solo, used in the groups. Ortho Solo is a fluoride-releasing universal sealant and bond enhancer. It is composed of dimethacrylate resins, barium glass, fumed silica, sodium hexafluorosilicate, and ethanol. According to the manufacturers, Ortho Solo incorporates a bond-enhancing property that improves adhesion to the tooth at the adhesive interface, hence reducing bond failures. High SBS value by use of Grengloo in our study was also in agreement with the results of Bayani et al [20]who reported the mean SBS to be 27.55±3.27MPa at 20 seconds and 31.25±2.43MPa at 40 seconds when compared to that of Transbond Plus. Ekhlassi et al [7]reported the SBS of Grengloo to be 11.3 ± 2.8 MPa at 24 h after

bonding, which was lower than the value, obtained in the current study. Difference in methodology and enamel preparation method may explain the difference in the results. Similar result was reported by Duer et al [6]who reported lower SBS value for Grengloo at 24 hours. Lower amounts of SBS in their study compared to the present study may be attributed to the use of bovine teeth instead of human teeth, or the use of ground enamel surface instead of natural intact enamel surface. They used Transbond etching gel and Transbond primer for all the study groups and cured all the adhesives for 20 s. When the results of the ARI were evaluated for Group 1 and Group 2, it was noted that the most common result for Group 1 was score 3 (%), where all the adhesives remained in the enamel after debonding. But in Group 2, the ARI score of 2 was more frequent than score of 3. The majority of bond failures in Grengloo adhesive occurred within the adhesive layer, which is consistent with the results of a study by Türkkahraman et al.[12] Duer et al[6] reported that Grengloo tested at 15 minutes and at 24 hrs had the lowest average ARI score than Transbond Plus which had the highest average ARI score which is in concurrent with the present study. In the present study as well as in the study by Türkkahraman et al the majority of debonding at enamel-adhesive interface occurred with Transbond Plus adhesive, suggesting a potential risk of enamel damage with the use of this adhesive. EDX analysis revealed that there is statistically significant difference between Group 1 compared to Group 2.The mean amount of calcium (Ca%) and phosphorus (P%) from the scanned metal brackets were 3.69% and 2.08% respectively for group 1 and this values were 4.37% and 2.23% respectively for group 2. This difference in the values indicates the possible association between the increased Shear bond strength, decreased ARI score and the loss of enamel.

In the present study the mean SBS of Grengloo with Orthosolo primer and that of Transbond XT with conventional primer was14.75 MPa and 12.79 MPa respectively. Group 1 had a higher shear bond strength compared to Group 3 which is in consistent with the results of Delavarian et al, [21]reported 22.95±5.20 MPa as mean SBS of Grengloo when compared to Transbond XT which had a mean SBS of 13.71±3.57 MPa. Bayani et al[20] reported that Grengloo provided an SBS higher as 31.25±2.4MPa and 27.55±3.4 MPa after 40 s and 20 s of curing respectively which is in correlation with our study. When the results of the ARI were evaluated for Group 1 and Group 3, it was noted that the most common result for Group 1 and Group 3 was score 3, where all the adhesives remained in the enamel after debonding. Delavarian et al[21] had a similar observation that there was no statistical difference was noted in ARI scores between Grengloo and Transbond XT using metal brackets. EDX analysis revealed that there is no statistically significant difference between Group 1 compared to Group 3.The mean amount of calcium (Ca%) and phosphorus (P%) from the scanned metal brackets were 3.69% and 2.08% respectively for group 1 and this values were 1.50% and 0.66% respectively for group 3. This mild difference in the values indicates the possible association between the increased shear bond strength and the loss of enamel.

In the present study the mean SBS of Transbond Plus and that of Transbond XT with conventional primer was13.97 MPa and 12.79 MPa respectively. The shear bond strength of Group 2 was more than Group 3 which was in contrast with Romano et al [22]who reported increased SBS of Transbond XT when compared to Transbond Plus. No significant difference was reported between Transbond Plus and Transbond XT by Duer at al[6]. When the results of the ARI were evaluated for Group 2 and Group 3, it was noted that the most common result for Group 3 was score 3 where all the adhesives remained in the enamel after debonding and for Group 2 was score 2. Romano et al [22]had similar finding where the ARI scores of samples showed most fractures occurred at bracket /composite interfaces. EDX analysis revealed that there is statistically significant difference between Group 2 compared to Group 3.The mean amount of calcium (Ca%) and phosphorus (P%) from the scanned metal brackets were 4.37% and 2.23% respectively for group 2 and this values were 1.50% and 0.66% respectively for group 3. This difference in the values indicates the possible association between the increased shear bond strength and the loss of enamel.

CONCLUSION

Based on the result of this study, it can be concluded that

- The metal brackets bonded with Grengloo and Transbond Plus color changing adhesive had the highest shear bond strength when compared to the conventional Transbond XT adhesive.
- Metal brackets bonded with Transbond Plus had the highest enamel loss, as evidenced by the calcium and phosphorous elements revealed in EDX.
- There was no significant difference in enamel loss between Grengloo and Transbond XT, as evidenced by the calcium and phosphorous elements revealed in EDX.
- Bond failure of Grengloo is more likely to occur at the adhesive enamel interface.

GLOSSARY OF ABBREVATION

ANOVA	Analysis of Variance
ARI	Adhesive Remnant Index
Bis-EMA	Ethoxylated bisphenol dimethacrylate
Bis-GMA	Bisphenol A-glycidyl Dimethacrylate
Ca	Calcium
CCA	Color Change Adhesive
EDAX or EDX	Energy dispersive x-ray spectrometry
MPa	Mega Pascal
N	Newton
P	Phosphorous
P- VALUE	Probability Value
SEM	Scanning Electron Microscope
SD	Standard Deviation
SBS	Shear Bond Strength

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