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SHEAR BOND STRENGTH OF ORTHODONTIC CONVENTIONAL METAL BRACKETS TO ENAMEL USING TWO DIFFERENT ORTHODONTIC COMPOSITES AND ADHESIVE SYSTEMS: AN IN-VITRO STUDY

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ABSTRACT

Objective: To test the claim of the manufacturers about the necessity of combining the orthodontic primers and adhesive pastes from the same brand in order not to compromise the bond strength to enamel. **Materials and methods:** Eighty human premolar teeth with intact buccal surfaces were randomly divided into four groups with twenty teeth per group. Regarding Group I and Group IV, the same brand of primers and adhesive pastes was used from 3M™ Transbond™ XT and Ormco™ Grengloo™ bonding systems, respectively. Conversely, Group II and Group III involved using non-corresponding primers and adhesive pastes from those brands. The miniMaster series® brackets from the American Orthodontics™ company were used for bonding to enamel surfaces. After debonding with a universal testing machine, the Shear Bond Strength (SBS) values were obtained and compared. Then, the adhesive remnant index (ARI) was scored using qualitative visual scoring. **Results:** The mean SBS values for Groups I, II, III, and IV were 11.26, 8.07, 9.98, and 10.04 MPa, respectively. The highest mean was observed in Group I, while the lowest was in Group II. There were statistically insignificant differences in SBS, observers' ratings of ARI, failure modes, and distribution of ARI scores. **Conclusion:** Despite using non-corresponding orthodontic primers and adhesives from different manufacturers during bonding to enamel surfaces, good bonding strength values can be obtained.

KEYWORDS*:* Adhesive, bond, brackets, primer, shear, score.

INTRODUCTION

Buonocore introduced the enamel-etching technique that made direct bonding of orthodontic accessories, which used to be welded to metal bands, possible [(1)]. The demands for high bond strength for successful bonding in orthodontics were less than that needed for restorative dentistry. Many studies recommended the minimal required bond strength value which should range between 5.9 and 7.8 MPa in order to withstand the applied forces during treatment [(2-5)]. Moreover, a very high bond strength value can be statistically significant, but not necessarily provide better clinical performance than a lower one [(6,7)]. Furthermore, the high bond strength may lead to damaging the underlying tooth structure during debonding [(8)].

The global inflation and economic crisis have adversely affected the market availability of orthodontic materials. Therefore, the question that may pop to an orthodontist during bonding a fixed orthodontic appliance in a private dental practice may be stated as "Would combining different

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manufacturer bonding agents and pastes affect the bond strength of orthodontic metal brackets to enamel? ".

Direct bonding of orthodontic brackets to the enamel may involve a separate etching step as a feature in three-step and two-step adhesive techniques. Conversely, the all-in-one adhesive technique does not require a separate etching step. In the current study, the adhesive systems were two-step light-cured adhesives. There was a difference in the chemical composition of the used adhesive systems. According to the manufacturer, the Transbond™ XT adhesive system involved Bisphenol A Diglycidyl Ether Dimethacrylate (BISGMA) as a monomer and triethyleneglycol dimethacrylate (TEGDMA) as a co-monomer. Conversely, the Grengloo™ adhesive system contained 2-hydroxyethyl methacrylate (HEMA) as a monomer and 3-trimethoxysilylpropyl methacrylate (TMSPMA) as a co-monomer. Therefore, investigation of the cross-compatibility with these chemically different adhesive systems may pave the way for using the readily available orthodontic primers from different manufacturers in clinical orthodontic bonding of conventional metal brackets to an enamel surface, especially in economic crises. However, it was hypothesized that the SBS of adhesive orthodontic paste with its corresponding company-based bonding agent would be greater than the obtained SBS by using adhesives from non-corresponding different manufacturers.

Unluckily, the cross-compatibility existence between different manufacturers has not been thoroughly investigated in the orthodontic literature. The current study aimed at testing the effect of bonding orthodontic appliances with combinations of different manufacturer bonding agents and pastes on the Shear Bond Strength (SBS). Thus, evidence-based clinical recommendations for direct bonding of orthodontic accessories to enamel can be withdrawn for the Egyptian and other global orthodontic communities, especially during an economic crisis.

MATERIALS AND METHODS

The materials used in current in vitro study are displayed in table (1). Regarding Group I and Group IV, they involved primers and adhesive pastes from the same brands; 3M™ Transbond™ XT3M™ Unitek™, (Monrovia, CA, USA) and Ormco™ Grengloo™ (Ormco™, CA, United) primers and adhesive pastes from those brands.

TABLE (1) The used materials and their factorial design.

Exposure / Groups	Primer (Light-cured)	Adhesive paste (Light-cured)
Group I	Transbond™ XT	Transbond™ XT
Group II	Transbond™ XT	Grengloo™
Group III	Ortho solo bond™	Transbond™ XT
Group IV	Ortho solo bond™	Grengloo™

One hundred First premolar human teeth were recruited after extraction for orthodontic or periodontal reasons from the dental clinic of the Surgery Department, Faculty of Dentistry, Cairo University. Teeth were stored in distilled water, which was changed monthly. The maximum storage time of the teeth was six months until usage. Meanwhile, the sample size calculation revealed that the total number of samples for the current study samples should be eighty teeth. Regarding sample size calculation, the independent t-test was performed by using P.S. power 3.1.6. The mean difference was 0.5 when the power was 85% and type I error probability was 0.05. After conducting the current study, a power analysis was carried out and showed that the used sample size of this study was appropriate for testing the hypothesis of the study. However, all included teeth had intact buccal enamel surfaces with a maximum storage time of six months. From the collected teeth, any teeth with the following criteria were excluded from this study; Teeth with:

1. Erosion, abrasion, surface demineralization, or decay.
2. Traumatic damage provoked by forceps during the extraction procedure.
3. A history of extraction from patients with uncontrolled systematic diseases.

FIG (1) Tooth embedded in self-cured acrylic resin. Uncovered buccal surfaces above the CEJ.

After applying this study's inclusion and exclusion criteria to the collected teeth, twenty teeth were disqualified, while only eighty teeth were enrolled in this study. Then, soft tissue remnants and calculi on the external root surface of the eighty samples were removed mechanically by a periodontal scaler, and then the teeth were immersed in a 5.25% sodium hypochlorite (NaOCl) solution for 15 minutes to disinfect them. Afterwards, the teeth were sterilized in a class B autoclave for fifteen minutes at a temperature of 121 C. Then, after autoclaving, teeth were stored in a sterile isotonic solution until adhesive application during the day of sample preparation. The last step of preoperative preparation of the samples was to embed the premolars in self-cured acrylic resin, with their buccal surfaces left uncovered above the CEJ figure (1).

Before etching of the enamel surface, the enamel was cleaned by polishing with water and pumice. After polishing, the enamel surface was thoroughly rinsed and the surface was examined for the subsequent etching process. The samples were divided into four groups with twenty teeth per group. Then, a 5 by 3 mm area was etched with 37% orthophosphoric acid gel (Meta Biomed, Republic of Korea) for 30 seconds, and rinsed with water for 30 seconds. Then, the tooth was accurately dried with moisture and oil-free air to achieve a dull, frosty white appearance.

Then, according to the group allocation, a thin layer of correlated adhesive primer to its related group was applied and with compressed air, the surplus of an adhesive primer was delicately removed and light-cured for previously mentioned primers for 10 sec with an LED light curing device (Model: CV-215(G1), Cicada 1 Sec Light Cure Unit, China)

The used conventional metal brackets (American Orthodontics™ , Master Series®, Mini Master® brackets, Washington, USA) were premolar stainless steel brackets. Brackets were transferred to the ideal position. The excess composite was removed with a dental explorer, avoiding any slight movement of the fitted bracket to avoid disturbing the setting of the used adhesive. The used composite was light-cured for 40 seconds. A sample before debonding with a universal testing machine was illustrated in figure (2).

FIG (2) Light-cured directly bonded conventional metal bracket with its correlated light-cured orthodontic adhesive system to the buccal enamel surface of a mounted premolar tooth.

The bonded samples were stored in water at 37°C for 24 hours before debonding. The samples of each group were stored separately from the samples of other groups. To avoid assessment bias, the assessor of shear bond strength was blinded and did not know any data about the used materials. The samples were debonded using a universal testing machine (Model: 2710-113, Instron, Norwood, MA, USA). The specimens were secured in a jig attached to the base plate of a universal testing machine

A chisel-edge plunger was mounted in the movable crosshead of the testing machine and was positioned to allow a shear force to be applied to the enamel-resin interface. A 0.5 mm/minute crosshead speed was used, and the maximum load necessary to debond the bracket was recorded. The force required to debond the brackets was measured in Newtons (N), and the shear bond strength (SBS) [1 megapascal (MPa) = 1 N/mm2] was calculated by dividing the force values by the bracket base area. Upon debonding, a deboned sample was illustrated in figure (3).

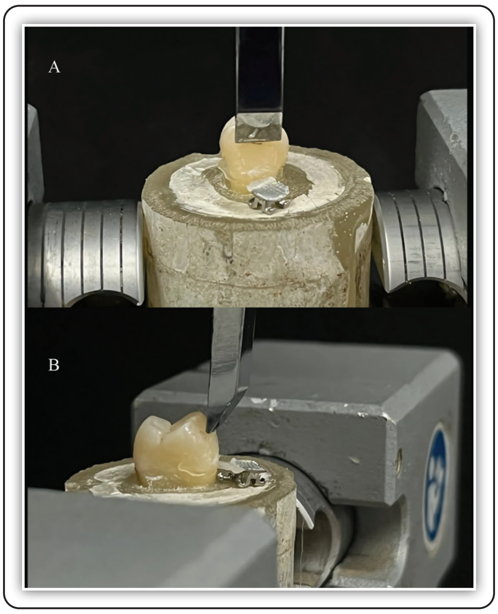

FIG (3) After debonding by the universal testing machine showing a debonded sample. (A) Frontal view. (B) Side view

Each debonded bracket was placed with its related sample in the same coded and numbered envelope. Then, the envelope was resealed and sent back to the principal investigator for assessment of the adhesive remnants left on the debonded enamel surface which was called observer 1. Afterwards, according to ARI by Årtun and Bergland[9], observer 1 scored the eighty samples. Then, the co-author, H.D. scored with the same ARI index criteria, called observer 2, but separately from observer 1 to provide the statistician with the required data for the inter-observer reliability test. The debonded samples were scored thoroughly by qualitative visual scoring following the criteria for ARI of Artun and Bergland[9] that stated:

Score 0 = no adhesive left on the tooth.

Score 1 = less than half of the adhesive left on the tooth.

Score 2 = more than half of the adhesive left on the tooth.

Score 3 = all adhesive left on the tooth, with a distinct impression of the bracket mesh.

Statistical analysis

Data were statistically analyzed by Microsoft Excel® 2016 (Microsoft Cooperation, USA). Statistical Package for Social Science (SPSS)® Ver. 24 (IBM Product, USA). and Minitab (Minitab LLC, USA) ® statistical software Ver. 16.

RESULTS

In group 1, Transbond™ XT primer and its adhesive showed the highest observed mean shear bond strength at 11.26 MPa. Conversely, group 2, Transbond™ XT primer with Grengloo™ adhesive paste exhibited the lowest mean bond strength at 8.078 MPa. Both groups 3 and 4 showed similar mean values around 10 MPa. The former was 9.98 MPa while the latter was 10.04 MPa. Descriptive statistics were computed to provide an initial overview of the adhesive systems' performance by highlighting variations in shear bond strength data among the four tested groups and displayed in table (2).

TABLE (2) Descriptive statistics of Shear Bond Strength (MPa) of orthodontic conventional metal brackets to enamel using cross orthodontic composites and adhesive systems combinations:

	Group 1	Group 2	Group 3	Group 4
Mean	11.26	8.078	9.984	10.04
Std. Deviation	4.835	6.081	5.592	7.434
Std. Error of Mean	1.081	1.360	1.250	1.662
Lower 95% CI	8.997	5.232	7.367	6.563
Upper 95% CI	13.52	10.92	12.60	13.52

There were statistically insignificant differences in SBS values between the four groups. A series of linear regression analyses were used to predict the value of SBS (MPa) based on the value of Maximum Compressive Load (N). Linear regression analyses revealed a very strong linear relationship between the two previously mentioned variables in all groups. The F-statistic was extremely large with a p-value <0.0001, indicating that the relationship between Maximum Compressive Load and Shear Bond Strength was statistically significant. Maximum Compressive Load was an excellent predictor of Shear Bond Strength for the study combinations of primer and adhesive. Tukey's post-hoc test was applied to compare the Shear Bond Strength between each group against every other group. Non of the comparisons yielded were statistically significant. See table (3).

Regarding the adhesive remnant index data, it were illustrated in table (4). There was a perfect agreement between the two observers for the groups 1 and 3, while a fair agreement was noticed between the two observers for the groups 2 and 4. Chi-square tests yielded p-values greater than 0.05 for all groups (ranging from 0.9643 to >0.9999) which indicated no statistically significant differences between the observers' ratings.

Bland-Altman analysis of agreement showed no bias (0.000) for groups 1 and 3, confirming perfect agreement. groups 2 and 4 showed a small standard deviation of 0.8165 which indicated some variability in the observers' scores but still relatively close agreement. There were non-significant differences in bond failure modes and the distribution of ARI scores with the predominance of scores 3 and 4 in ARI index.

TABLE (3) Tukey's Multiple Comparison Statistics of Shear Bond Strength (MPa) of Orthodontic Conventional Metal Brackets to Enamel Using Cross Orthodontic Composites and Adhesive Systems:

	Mean 1	Mean 2	Mean Diff.	SE of diff.	P-value	Significance
Group 1 vs. Group 2	11.26	8.078	3.182	1.916	0.3515	Insignificant
Group 1 vs. Group 3	11.26	9.984	1.276	1.916	0.9095	Insignificant
Group 1 vs. Group 4	11.26	10.04	1.219	1.916	0.9201	Insignificant
Group 2 vs. Group 3	8.078	9.984	-1.906	1.916	0.7529	Insignificant
Group 2 vs. Group 4	8.078	10.04	-1.964	1.916	0.7355	Insignificant
Group 3 vs. Group 4	9.984	10.04	-0.05768	1.916	>0.9999	Insignificant

TABLE (4) Observer agreement statistics of adhesive remanent index (ARI) of orthodontic conventional metal brackets to enamel using cross orthodontic composites and adhesive systems:

Groups	Observers	ARI 0	ARI 1	ARI 2	ARI 3	Chi-Square, df	P-value	Bias±SD (Bland-Altman Analysis of Agreement)
Group 1	Observer 1	5	7	1	7	0.000, 3	>0.9999 (NS)	0.000±0.000
	Observer 2	5	7	1	7			
Inter-observer assessment (Kw)		1 *(> 0.8: Nearly perfect agreement)*						
Group 2	Observer 1	4	12	2	2	0.1829, 3	0.9803 (NS)	0.000±0.8165
	Observer 2	3	13	2	2			
Inter-observer assessment (Kw)		0.333 *(0.21-0.4: Fair agreement)*						
Group 3	Observer 1	4	7	3	6	0.000, 3	>0.9999 (NS)	0.000±0.000
	Observer 2	4	7	3	6			
Inter-observer assessment (Kw)		1 (> *0.8: Nearly perfect agreement)*						
Group 4	Observer 1	5	7	2	6	0.2769, 3	0.9643 (NS)	0.000±0.8165
	Observer 2	5	6	3	6			
Inter-observer assessment (Kw)		0.385 *(0.21-0.4: Fair agreement)*						

ARI 0; no adhesive left on the tooth.
ARI 1; less than half of the adhesive left on the tooth.
ARI 2; more than half of the adhesive left on the tooth.
ARI 3; all adhesive is left on the tooth, with a distinct impression of the bracket mesh.
Kw; Weighted Kappa. NS; Insignificant Difference using the Chi-Square test

DISCUSSION

Bonding orthodontic brackets is of supreme importance to the overall success of orthodontic treatment[7]. The current study aims to test the manufacturers' claim about the necessity of combining dental orthodontic adhesive and resin-based composite from the same manufacturer in order not to compromise the bond strength of the enamel. It was hypothesized that the SBS of adhesive orthodontic paste with its corresponding company-based bonding agent would be greater than the obtained SBS by using adhesives from non-corresponding different manufacturers.

In the current study, the selection of the two resin adhesive systems was based on their credibility in literature as separate orthodontic adhesive systems. In other words, they are considered the gold standard and most widely used orthodontic adhesives in the literature [18]. Also, these materials and the conventional metal brackets; mini-master series® from American Orthodontics were used due to their availability in Egypt where the current study was conducted.

A few studies have been published on the effects of storage conditions on enamel [12,13]. However, the properties of enamel strongly affect the success or failure of restorative materials [12-15]. Teeth were stored in distilled water for a maximum of six months because long periods of storage in saline solution were not recommended because it may result in soften the enamel surface [12]. The distilled water was chosen because it does not alter enamel surface properties especially for long-storage period [15].

The literature advocates that the minimum SBS of orthodontic bonding should be in the range of 5.9 to 7.8MPa, while the maximum SBS must not cross the enamel fracture threshold which is around 14MPa [16,17]. The current study demonstrated that the mean SBS values of bonded brackets using Transbond™ XT and Grengloo™ light cure adhesive systems and their combinations were above the clinical acceptability level of 5.9 to 7.8MPa.

The data analysis outcome of this study recommended partial acceptance of alternate hypothesis. There was a slightly higher difference in SBS values related to groups I and IV; company-based corresponding primer and adhesive paste, than that of non-corresponding ones. However, that SBS difference was statistically and clinically insignificant.

Regarding enamel bonding, although Sharma et al.'s study did not aim at testing the cross compatibility effect of adhesive systems, their fourth orthodontic adhesive was a combination of Transbond XT™ paste with Transbond XT Plus™ primer instead of conventional Transbond XT™ primer[5]. However, the main limitation of their study was that there was no actual cross-compatibility testing because Transbond XT Plus™ primer and conventional Transbond XT™ primer had similar chemistry from the same manufacture. Unlike their study, the current study compared the cross-compatibility of non-corresponding combinations of adhesive paste and bonding agents from different manufacturers with control groups of corresponding adhesive paste and agents from the same manufacturer.

Regarding dentin bonding, Seitz et al[19] evaluated the Shear Bond Strength (SBS) by combining adhesive systems and resin cement from different manufacturers for dentin bonding. Their study showed that combining adhesive and cement from other manufacturers did not compromise dentin bonding [19]. The limitation of their work was their assessment of dentin bonding which is not applicable in orthodontic bonding. Unlike Seitz et al. study, the current study focused on usage of non-corresponding orthodontic adhesive paste and primers with enamel as the substrate to be tested instead of dentin for orthodontic bonding.

Besides, the orthodontic bond strength requirement already has much lower bonding value demands and different durability criteria than that for permanent restorative bonding [20]. Moreover, orthodontic bonding is temporary bonding and should withstand orthodontic forces during orthodontic treatment, yet at the same time, it has to be weak enough in order not to damage the underlying hard tooth structure during the debonding of brackets [7]. Therefore, the current study was conducted to provide the community with evidence-based clinical recommendations, especially in periods of shortage of orthodontic materials in the market during an economic crisis.

A direct relation was found between ARI and SBS [21]. High ARI scores were associated with higher bond strengths than those for lower ARI [21]. However, previous studies had shown no significant differences in ARI scores between qualitative visual scoring, elemental mapping, and scanning electron microscopy analysis[22,23]. On the other hand, the reliability of how magnification affects adhesive remnant interpretation has been questioned[24]. Therefore, qualitative visual scoring was used by the investigator and co-supervisor.

Bond failures can occur in enamel-adhesive interface; score 0 and 1, or bracket-adhesive interface; scores 2 and 3[24]. The bracket-adhesive interface failure are the most advantageous failure site for safe debonding [21,26]. This is explained by the presence of most of the adhesive remains on the bonding surface which decreases the possibility of enamel fracture. On the contrary, a bond failure at the enamel-adhesive interface is considered dangerous failure site because there is increased possibility of enamel fracture during debonding [25]. In the current study, the bond failure mode had been frequently observed at the bracket-adhesive contact in the four groups. Many samples showed more than half of all adhesives was left on the sample surface which increased scores 2 and 3 in the overall scoring.

CONCLUSIONS

Within the limitations of the current study, the following conclusions were drawn from the laboratory study:

1. SBS values obtained with the use of both tested orthodontic composites and adhesive systems and their non-corresponding combinations of adhesive pastes and primers exceeded the clinically recommended value (5.9 MPa to 7.8 MPa).
2. Although there was a difference in the obtained SBS values which was slightly greater in favor of the groups with corresponding company-based primers and adhesive paste, yet that difference was statistically and clinically insignificant.
3. There was a non-significant difference in bond failure modes and the distribution of ARI scores between the tested orthodontic composites and adhesive systems.
4. The use of readily available orthodontic primer from different manufacturers in clinical orthodontic bonding of conventional metal bracket to an enamel surface is practical, if there is no corresponding primer and adhesive paste from the same manufacturer available.

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