Shear Bond Strength and Bonding Properties of Orthodontic and nano Adhesives: A Comparative *In-Vitro* Study

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Abstract

Introduction: Nano restorative composites have been successfully used in restorative dentistry and have high strength and wear resistance. Conventional orthodontic adhesives also possess optimal strength to withstand occlusal forces. This study was done to compare the shear bond strength (SBS) of orthodontic bracket after bonding with nanorestorative composite and orthodontic adhesives. **Materials and Methods:** This *in-vitro* experimental study used sixty extracted teeth (divided into two groups). In Group A (n = 30), the brackets were bonded with Filtek Z350 (3M/Unitek, Monrovia, California, USA), a nano ceramic restorative composite, and in Group B (n = 30), the brackets were bonded with Transbond XT (3M/Unitek, Monrovia, California, USA), a conventional orthodontic adhesive. The SBS of the orthodontic brackets was measured using a universal testing machine. The modified 0–5-scale adhesive remnant index (ARI) was used to assess the amount of adhesive on enamel and bracket surfaces. The surface topography was observed to evaluate enamel damage. **Results:** The mean (standard deviation [SD]) SBS of 11.07 (1.96) Mega Pascal (MPa) was observed with Filtek Z350, whereas the group bonded with Transbond XT showed the mean (SD) SBS of 12.18 (1.69) MPa. The results showed that Transbond light curing adhesive produced higher SBS than Filtek, but the difference was statistically insignificant (P = 0.088). The comparison of ARI score between the two groups also showed statistically insignificant difference (χ^2 = 4.764, df = 5, P = 0.445), and most of the teeth in both groups exhibited score 3 (63%), showing the least damaging mode of bond failure to the enamel bracket interface. **Conclusion:** There was no significant difference in the mean SBS of Filtek Z and Transbond XT adhesives. Both materials showed optimum bond strength to withstand occlusal forces.

Keywords: *Adhesive remnant index score, cohesive bond failure, nano restorative adhesives, orthodontic adhesives, shear bond strength*

Introduction

Since the introduction of an acid etch bonding technique by Buonocore in 1955, the concept of bonding various resins to enamel is being used widely in dentistry, including the bonding of orthodontic brackets.[1] After 1966, when earliest orthodontic brackets were bonded directly to enamel surface, adhesive systems have undergone a considerable evolution.[2]

The science of nano particles is doing wonders in different fields of science and technology. Nanoparticles are being incorporated in different dental materials to enhance the efficacy. Mesoporous nanoparticles are added to adhesives to incorporate antimicrobial properties, hence reducing the chances of recurrent caries. A method was developed to encapsulate and release chlorhexidine from adhesives with mesoporous silica nanoparticles. In addition, the nanoparticles in the form of thin film of nitrogen-doped titanium dioxide are coated on the surfaces of orthodontic appliances to prevent microbial adhesion or enamel demineralization during orthodontic therapy.[3]

A new generation of bioactive resins is developed with anticaries activities. These consist of antimicrobial adhesives, bonding agents, and other resins containing quaternary ammonium methacrylate to suppress plaque buildup and bacterial acid production. Nanosilver particles (NAg) were added to the resins which greatly reduced the biofilm growth without negatively affecting the bond strength or color of the material. Nanoparticles of amorphous calcium phosphate were added into resin. These resins have properties to combat caries, suppressing biofilm

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acids and promoting remineralization, especially with subgingival margins to inhibit periodontal pathogens, combat periodontitis, and protect the periodontium.[4]

Resin adhesives can be arranged by filler particle size. Ideally, it should contain the smallest particles. Most of the resins available in market earlier contained macrofillers.[5,6] Recently, researchers have come to the conclusion that the best adhesive resins should ideally consist of micron (μm)-sized particles combined with nano-sized particles to provide high strength, less shrinkage, high polishability, and better optical properties.[7]

The incorporation of nano resins in the adhesives has opened up new avenues as far as strength and esthetics is concerned. It also adds higher compression strength, flexural strength, elastic modulus, coefficient of thermal expansion, water absorption, and wear resistance.[8]

These nanoparticles also enhance the hybrid layer, increase marginal seal, and reduce polymerization shrinkage due to their higher filler content. Furthermore, nano-filled bonding agents have shown satisfactory bond strength to enamel and dentin, and can be utilized for direct and indirect restorations.[9-12]

When bonding an orthodontic bracket, the bond strength should be sufficient to withstand the forces of mastication and stresses exerted by arch wires. However, there are many factors that can potentially contribute to the bond strength between enamel and the orthodontic bracket, including the type of enamel conditioner, acid concentration, length of etching time, composition of the adhesive, bracket base design, bracket material, oral environment, as well as the skill of clinician.[13] As re-bonding of brackets could be a time consuming and challenging process, achieving appropriate bond strength is an important clinical objective.[14] While various types of adhesives such as micro-filled, microhybrid, and flowable are available, it is likely that nano-filled adhesives may replace other types of adhesives in the near future.[15]

Despite the extensive applications of nano-adhesives in restorative dentistry, their use is less pondered and practiced in orthodontics.[16]

The aim of this *in-vitro* study, therefore, is to assess the shear bond strength (SBS) of orthodontic brackets bonded with the conventional orthodontic adhesives and newer nano-filled restorative adhesives and also to determine the debonding characteristics by using modified adhesive remnant index (ARI) score. The null hypothesis of the study was that there is no difference between the bonding strength of orthodontic and restorative adhesives.

Materials and Methods

This experimental *in-vitro* study was done in the Department of Orthodontics and Conservative Dentistry, College of Dentistry, Qassim University. The study was approved by the research board of the Qassim University #2990.

Study sample

Sixty extracted teeth were collected. All the specimens were with intact crowns and were free from attrition, hypoplastic areas, cracks, gross irregularities, decays, and fractures They were cleaned using an ultrasonic scaler to remove tissue tags and plaque and were polished and stored in 0.1% aqueous thymol solution at 370°C for 3 months. For the purpose of mounting on an Instron testing machine, the samples were prepared in the following manner. 80 mm × 10 mm × 5 mm brass bars were fabricated and invested in a dental plaster to produce a mold. Open-ended cylinders of 20 mm height and 15 mm internal diameter were cut out of polyvinyl chloride (PVC) pipe. Each PVC cylinder was filled with orthodontic resin into which a premolar tooth was embedded, leaving its crown exposed and parallel to a long axis of the cylinder. All the teeth were embedded in the acrylic, and the groups were color coded. The teeth in both the groups were mounted in such a way that the buccal surface would be exposed and a jig would be fabricated for mounting on an Instron universal testing machine (Model no: 5965 K).

The sample was randomly assigned to two groups of thirty each as Groups A and B. In Group A (n = 30), the teeth were etched with 37% phosphoric acid gel (Dentsply, York, PA, USA) for 30 s. After that, the teeth were rinsed for 20 s and then dried with stream of air for 20 s to appear opaque and frosty. Then, the preadjusted edgewise brackets (Gemini brackets, 3M/Unitek, Monrovia, California, USA), 0.022” bracket slot, were bonded to the etched enamel using light cure FILTEK Z350 (3M/Unitek, Monrovia, California, USA), a nano ceramic restorative adhesive. The brackets were seated and positioned firmly in the middle third of the buccal enamel surface. The brackets were fixed on the tooth surface, with bracket placing plier (3M/Unitek, Monrovia, California, USA), and the excess material was removed.

In Group B (n = 30), all the steps similar to Group A were performed on the samples, except that the brackets were bonded with light cure Transbond XT (3M/Unitek, Monrovia, California, USA), a conventional orthodontic adhesive.

The adhesive paste was cured for 20 s from two directions using a visible light-curing unit (XL300; 3M/Unitek Dental Products, Monrovia, California). All specimens were stored in distilled water at 37°C for 24 h.

Afterward, the teeth in both the groups were mounted individually on a universal testing machine for the debonding procedure. All the above-mentioned procedures were observed by a group of two dentists comprising of an orthodontist and a restorative dentist to minimize the bias and error. These observers were kept blind to the group that particular teeth belonged to.

Shear bond strength assessment

The SBS was tested using the Instron testing machine (model no: 5965 K) 24 h after bonding the brackets to enamel surface. Using a 5-mm metallic rod, the shear force was applied by the testing machine parallel to the height of contour of the teeth to the tooth–bracket interface in an occluso-gingival direction, with a 1-kn load cell at the crosshead speed of 0.5 mm/min. The bond strengths were calculated in Mega Pascal (MPa). A trained and calibrated observer did the whole procedure. The sample size remained constant throughout the study, with 0% dropout rate.

Adhesive remnant index

The mode of failure and the amount of adhesive resin remaining on tooth or bracket surface were determined by the 0–5 scale modified ARI developed by Bishara and Trulove.[17]

- Score 0 = No adhesive left on bracket
- Score 1= <25% of adhesive left on bracket
- Score 2 = 25% of adhesive left on bracket
- Score 3 = 50% of adhesive left on bracket
- Score 4 = 75% of adhesive left on bracket
- Score 5 = 100% of adhesive left on bracket.

The surface morphology of debonded tooth surface was examined clinically with naked eye to determine fractured surfaces, if any.

Statistical analysis

Statistical package SPSS software version 23 (IBM Corp., Armonk, N.Y., USA) was used for analysis. The mean of SBS was calculated using descriptive statistics and compared by using one-way analysis of variance; the level of significance was set at 0.05 ($P < 0.05$) with 95% confidence interval to check the null hypothesis. The Chi-square test was used to evaluate and compare the ARI score of the two groups.

Results

Descriptive statistics including mean, minimum and maximum values, and standard deviations of each group are summarized in Table 1. The mean SBS of 11.07 MPa was observed with Filtek Z350 (3M/Unitek, Monrovia, California, USA) (Group A), whereas Group B bonded with Transbond XT (3M/Unitek, Monrovia, California, USA) showed the mean bond strength of 12.18 MPa. The results showed that Transbond light-curing adhesive paste produced higher SBS than Filtek, but the difference was statistically insignificant ($P > 0.05$). The 95% confidence interval (−3–5.2) value establishes the confidence in null hypothesis. The null hypothesis of the study has been accepted.

The ARI scores for both the groups are displayed in Table 2. The highest percentage obtained by both the groups was of score 3, suggestive of cohesive type of bond failure at the enamel–bracket interface. The comparison of ARI score between the two groups showed no statistically significant difference between both the groups ($P = 0.44$) [Table 2]. The enamel surface of debonded specimens showed superficial cracks in the enamel on two teeth in Group B ($n = 2$). The ARI score of both these specimens was 5. No damages were observed in Group A.

Discussion

The aim of the present study was to measure and compare the SBS of nano restorative and conventional orthodontic adhesives. The results of this study showed that Transbond XT has a slightly higher mean SBS (12.18 MPa) when compared with Filtek Z350 (11.07 MPa), but the difference in the mean SBS of both the adhesives was not statistically significant ($P > 0.05$). The strength of Filtek Z350 was above the clinical range to successfully withstand the occlusal and orthodontic forces.

Preferable bond strength for restorations is different from that in orthodontics. In restorative dentistry, usually, the higher bond strength is more desirable, whereas in orthodontics, optimum bond strength is required. Lower bond strength can lead to frequent breakages of the bracket enamel bond, whereas higher bond strength can cause damage to the tooth surface during the debonding procedure.[18,19] Reynolds stated that a minimum bond

Table 1: Descriptive statistics of shear bond strength (Mega Pascal) and comparison between Filtek Z350 and Transbond XT adhesives

Group	*n*	Mean (SD) SBS	Range	95% confidence interval of the mean difference	*P* (ANOVA)
Filtek Z350	30	11.07 (1.96)	9.54-12.22	−3-5.2	0.088
Transbond XT	30	12.18 (1.69)	9.76-14.66		

SD: Standard deviation, SBS: Shear bond strength, ANOVA: Analysis of variances

Table 2: Percentage distribution, mean, and comparison of adhesive remnant index scores between Filtek Z350 and Transbond XT adhesives

Group	*n*	Score 0 (%)	Score 1 (%)	Score 2 (%)	Score 3 (%)	Score 4 (%)	Score 5 (%)	χ^2	*P*
Filtek Z350	30	3 (10)	3 (10)	6 (20)	10 (33)	5 (17)	3 (10)	4.764	0.445
Transbond XT	30	6 (20)	7 (23.3)	3 (10)	9 (30)	3 (10)	2 (6.7)		

χ^2=4.764, df=5, P=0.445

strength of 5.9–7.9 MPa could result in successful clinical bonding.[20] In this study, both the adhesives had higher bond strength than stated by Reynolds. Therefore, in addition to Transbond XT, Filtek Z350 is appropriate for orthodontic purpose and could be utilized for bonding. These results accepted the null hypothesis of this study. The studies done by Reynolds were *in vivo*, hence making the exact comparison difficult due to the difference in clinical conditions. *In-vitro* studies are not subjected to the rigorous oral environment, same humidity level, and heat conditions.

The findings of this study are consistent with the study done by Bishara *et al*.[15] According to their study, the nano-hybrid restorative adhesive can be effectively used for bonding the orthodontic bracket as there was no statistical difference between the SBS of hybrid and orthodontic adhesives.

On the contrary, the results of this study are inconsistent with the study done by Usyal *et al*.,[21] in which there was statistically significant difference between the SBS of the flowable nano and traditional orthodontic adhesives (Transbond XT). The bond strength was more than doubled with Transbond XT. This could be attributed to less advanced generation of nano adhesives and more flowable nature of the filler particles. Still, the mean SBS for flowable nano adhesives was sufficient to withstand load, as the minimum bond strength recommended for successful clinical bonding is 7 MPa.[22]

The quality of orthodontic treatment is being constantly improved with increasing sophistication of techniques and advances in orthodontic bonding adhesives that benefit both the patient and the clinician. Latest development in dental adhesives has led to better quality of bonding by refining its composition, dispensing systems and modes of curing. The main requisite of an orthodontic adhesive is to produce a strong and durable bond to withstand both occlusal and orthodontic forces during the course of treatment and at the same time to permit easy and damage-free bracket removal at the end of treatment.[23,24]

Bond failures are commonly said to be either cohesive failures or adhesive failures.[25] During bracket removal, bond failure at the adhesive–enamel or at the adhesive–bracket interface is known as adhesive failure. A cohesive failure is a failure in the bulk layer of the adhesive and is usually the desired mode of failure.[26] In general, a combination of cohesive and adhesive failures takes place.[27] The greater risk of damage to the tooth surface occurs in case of adhesive failure between resin and enamel.[28]

The ARI may oversimplify the complex issues of bond failure analysis, but it does allow for statistical analysis and cross-study comparisons. A review of the literature reveals that although many investigators modify an ARI system for the purpose of research, the one developed by Bishara and Truelove[17] is a reliable and comprehensive tool to carry out the adhesive failure analysis of a debonded bracket. When the ARI score was calculated [Table 2], the highest score exhibited by both Groups A and B was 3 (63% of teeth), which is suggestive of cohesive bond failure. This is the desired mode of bond failure between the tooth and bracket interface, as it leaves some of the adhesive on the bracket and some on the tooth surface, hence minimizing the enamel damage from adhesive. There was no statistically significant difference between the mean ARI scores of Filtek Z350 and Transbond XT ($P > 0.05$).

A study done by Uysal *et al*. also showed no significant difference in the ARI scores between the nano and traditional adhesive systems, and the mode of bracket failure was mostly at the adhesive–enamel interface.[13] The scores of 0 and 1 require extensive cleaning of the enamel, whereas the higher scores show the least amount of adhesive on the tooth surface and more chances of enamel crack and fracture. When the tooth surfaces were checked for fracture and cracks, two teeth showed cracks and both exhibited an ARI score of 5 and belonged to the Group B.

More studies of extended duration and long clinical trials are required to assess the complexities of bonding phenomena in a better way. In addition, further research and innovation in nano dentistry will open newer horizons in terms of stability and esthetics of bonding adhesives in orthodontics.

Conclusion

Both the Filtek Z350 and Transbond XT adhesives can be effectively and safely used to bond the orthodontic bracket to the enamel surface. Most of the bond failures with both the adhesives were cohesive in nature with least damage to the enamel surface. There was no significant difference in the mean SBS and ARI scores between both the adhesives.

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Conflicts of interest

There are no conflicts of interest.

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