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The Effects of Incorporating some Additives on Shear Bond Strength of Orthodontic Adhesive (An *In-vitro* Study)

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ABSTRACT

Background: *Evaluate the shear bond strength (SBS) and adhesive remnant index (ARI) after incorporation (1%) of silver, zinc oxide, or titanium dioxide nanoparticles to an orthodontic bonding agent.* ***Materials and methods:*** *Total 48 samples were selected and randomly divided into 4 equal groups (the 1st group was the control, while 2nd, 3rd and 4th were the test groups), containing 12 teeth each, according to the type of the nanoparticles (Ag, ZnO, or TiO_2 nanoparticles) which are incorporated to the orthodontic bonding agent (Transbond XT primer). Bond strength was measured using an Instron machine at a cross-head speed of 1 mm/min, and then the enamel surface of each tooth was inspected under a stereomicroscope (10X magnification).* ***Results:*** *There were no significant differences between all groups, ANOVA F-test was used to measure the mean shear bond strength for control, Ag, ZnO, or TiO_2 groups were 18.017, 16.921, 18.343, and 17.925 MPa respectively. Furthermore, chi-square test for adhesive remnant index showed highly significant differences between control and ZnO, and control and TiO_2, while significant differences between control and Ag, Ag and TiO_2, and ZnO and TiO_2, while a non-significant difference between Ag and ZnO.* ***Conclusion:*** *The incorporating of silver, zinc oxide, or titanium dioxide nanoparticles into orthodontic bonding agent at concentration of 1% has no effect on shear bond strength, on the other hand, in regard to ARI, a considerably more adhesive remains on the enamel surface following bracket removal in the test groups than the control group, and this will reduce the enamel damage after debonding.*

Keywords: Shear bond strength, Adhesive remnant index, Silver, Zinc oxide, Titanium dioxide, Nanoparticles

INTRODUCTION

One of the most undesirable side effects of orthodontic treatment was the formation of white spot, it can occur whenever the bacterial plaque is accumulated on enamel surface for long period [1]. Both the brackets and bonding adhesive materials may retain plaque as a result of this new site is susceptible to caries, in the patients who are undergoing to fixed appliance treatment [2,3]. Nanoparticles are incorporated into orthodontic adhesives/cement and can be coated on the surfaces of orthodontic appliances to prevent microbial adhesion or enamel demineralization in orthodontic therapy [4]. The nanotechnology has been useful in dentistry to cater the materials with improved mechanical properties and antibacterial effects [5].

The aims of the current study were to evaluate the shear bonding strength and adhesive remnant index pattern after the incorporation of silver, zinc oxide, or titanium dioxide nanoparticles to an orthodontic bonding agent.

MATERIALS AND METHODS

Teeth

Total 48 extracted human upper premolars teeth were included, kept in normal saline with 2% thymol crystals and examined grossly to be certain of an intact buccal enamel surface with no surface cracks caused by extraction forceps, free from caries or hypoplastic areas, and had not been pretreated with chemical agents, such as hydrogen peroxide [6-8]. The teeth were embedded in self-cured acrylic placed in L-shape metal plate, after mounting, the specimens were divided into 4 groups (12 teeth for each one), and coded by a marker so that the control group has “A” code, the group with silver NP coded with “B” mark, the group with zinc oxide NP coded with “C” mark, and the group with titanium dioxide NP coded with "D" mark to get randomization, the teeth were cleaned and polished with non-fluoridated pumice and rubber cup for 10 seconds.

Premolar Brackets

DISCOVERY® brackets (Dentaurum company/Germany) constructed from special corrosion resistance alloy of molybdenum steel made by an injection-molding process, Roth system, and the bracket base area is 13.62 mm^2.

Bonding Procedure

The 4 teeth groups were etched with 37% phosphoric acid and were applied for 30 seconds (according to manufacturer's instructions), then rinsed with water for 15-20 seconds and dried for 10 seconds [7,9-11].

Adhesive Preparation

The primer of the 1st group was left without any additives (control), while the in the 2nd group, 1% silver nanoparticles (80 nm, purity 99%) were incorporated to the primer [12-16], in the 3rd group, 1% zinc oxide nanoparticles (50 nm, purity 99%) were incorporated to the primer [12,14,17-19], and in the 4th group, 1% titanium dioxide nanoparticles 25 nm, (purity 99%) were incorporated into the primer [11,14,20,21]. Each mixture (a primer with one type of nanoparticle) was placed in a test tube covered with foil and mixed for 2 minutes using a vortex machine to create a uniform homogeneous mixture.

A thin uniform coat of Transbond XT primer (before and after adding either Ag, ZnO, or TiO_2 nanoparticles) was applied by an applicator on each tooth surface and cured for 15 seconds [13,14]. Then, brackets loaded with Transbond XT adhesive paste were bonded in all the samples and light cured for 10 seconds, after bonding, the teeth were stored in normal saline at 37°C for 24 hours [8,11,13,22,23].

Shear Bond Strength Test

Shear bond strength test was accomplished using a Tinius-Olsen Universal testing machine with a crosshead speed of 1 mm/minute and 5 KN load cell and a custom made chisel rod [8,11,13,24]. The specimen was placed in the lower jaw of the machine. An occluso-gingival load was applied at the enamel bracket interface from a knife-edge rod until debonding occurs [24-26]. The shear bond strength values were calculated in megapascal (MPa) by dividing the force value by the area of bracket base (13.62 mm^2) (Figure 1).

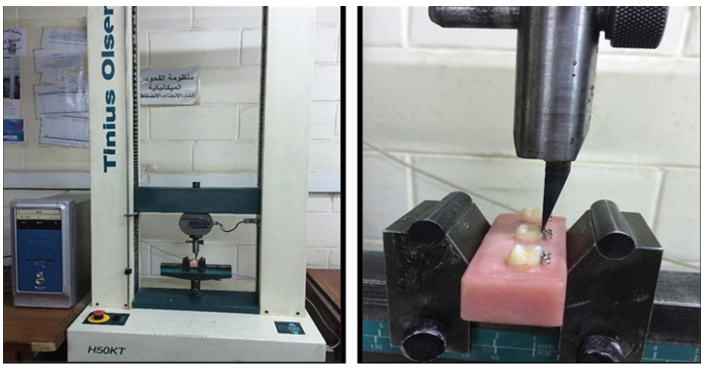

Figure 1 The sample fixed to the universal testing machine to test the shear bond strength

Estimation of Adhesive Remnant Index

The enamel surface of each tooth was inspected under a stereomicroscope (10X magnification) to determine the amount of the adhesive remaining on the tooth surface [8,13,27-32] (Figure 2).

Figure 2 Adhesive remnant index scores

Statistical Analysis

All statistical tests and calculations were made using statistical package for social science software (SPSS for windows, 19.0, Chicago, USA). Maximum, minimum, mean values, standard error, and standard deviations were calculated as a part of the descriptive analysis. Statistical significances were measured using one way (ANOVA) to discover the differences among the 4 groups and in regard to the adhesive remnant index, the comparison among the groups was done by using the chi-square test.

RESULTS AND DISCUSSIONS

Shear Bond Strength Test

Table 1 showed descriptive statistics and F-test analysis of variance (ANOVA) of the shear bond strength in different groups, there were no significant differences among the groups (Figure 3).

Table 1 Descriptive statistics and groups' differences of the shear bond strength (MPa) in various groups

Descriptive Statistics							Comparison (df=47)	
Groups	N	Mean	S.D.	S.E.	Min.	Max.	F-test	p-value
Control	12	18.017	1.507	0.435	16.080	20.930	2.16	
Ag	12	16.921	1.654	0.478	14.850	19.700		0.106[#]
ZnO	12	18.343	1.237	0.357	16.420	20.930		
TiO_2	12	17.925	1.352	0.390	16.110	20.410		
[#]Non-significant								

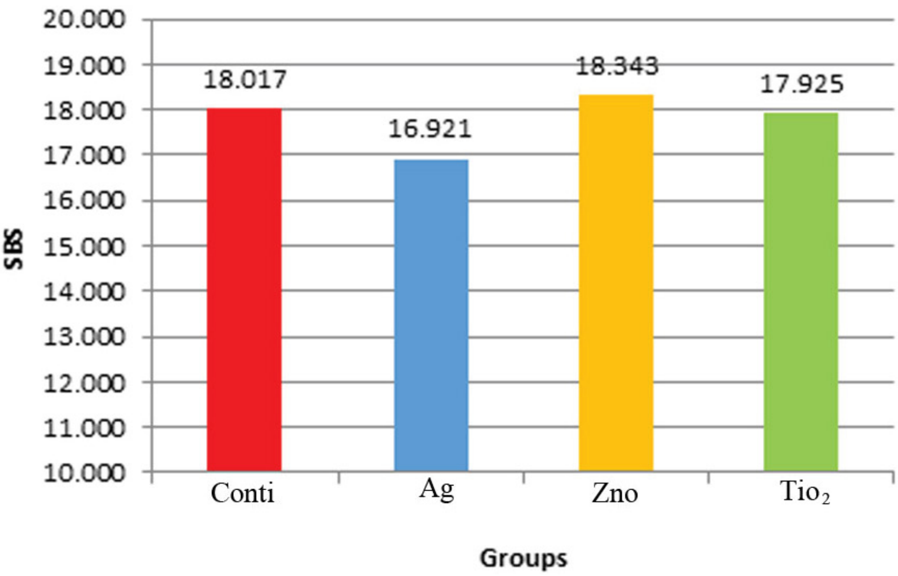

Figure 3 Groups' differences of the shear bond strength (MPa) in various groups

Adhesive Remnant Index

The ARI scores for the various groups were listed in Table 2. The results of the chi-square comparisons indicated that there were highly significant differences among the groups (p=0.000); as shown in Table 3.

Table 2 Frequency distribution and percentage of ARI scores in different groups

Groups	Score 0	Score 1	Score 2	Score 3	Total
Control	9 (75%)	1 (8.333%)	1 (8.333%)	1 (8.333%)	12 (100%)
Ag	2 (16.667%)	7 (58.333%)	2 (16.667%)	1 (8.333%)	12 (100%)
ZnO	0 (0%)	8 (66.667%)	2 (16.667%)	2 (16.667%)	12 (100%)
TiO_2	0 (0%)	2 (16.667%)	6 (50%)	4 (33.333%)	12 (100%)
Total	11 (22.917%)	18 (37.5%)	11(22.917%)	8 (16.666%)	48 (100%)
* ARI scores: 0=no adhesive remains on the tooth surface; 1=less than half the adhesive remains on the tooth surface; 2=more than half the adhesive remains on the tooth surface; 3=all the adhesive remains on the tooth surface					

Table 3 Comparison of ARI among different groups

Groups	Chi-Square test	d.f.	p-value
All	36.495	9	0.000***
Control-Ag	9.288	3	0.017*
Control- ZnO	15.111	3	0.000***
Control-TiO_2	14.705	3	0.000***
Ag-ZnO	2.400	3	0.365#
Ag-TiO_2	8.578	3	0.021*
ZnO- TiO_2	6.627	2	0.036*
*Significant; *** Highly significant; #Non-significant			

Shear Bond Strength

High mean shear bond strength value does not necessarily refer to a better clinical performance [33]. Consequently, the more important issue about shear bond strength in clinical orthodontic practice is to obtain an optimal bond strength value that permits safe detachment of fixed appliance components than to get the highest potential value [34]. In the current study, the mean SBS values in all groups (Ag, ZnO, and TiO_2) were higher than the clinically adequate SBS (5.9 to 7.8 MPa) as proposed by Reynolds [35], which means that all the adhesives can resist shear stress to adequate level. The result of the shear bond strength test revealed a no statistical significant difference between the control group and test groups, this means that the addition of nanoparticles at specific concentration (1%) did not have any effect on the physical properties of the tested materials, this result is in agreement with many researchers [11,13,16,17], and disagreement with Reddy, et al., [14]. This conflict may be due to the differences in the methodology involving the concentration of nanoparticles, size, and the methods of adding the nanoparticles. The result of the present study showed that the control group had the higher value of mean shear bond strength than Ag group, this difference may be due to the use of large particle size of Ag NP in this study, which was about 80 nm, which may act as a mechanical weak points (structural defects) and interferes with the curing of the material and decreases the mechanical properties and reduce the primer penetration into the etched enamel pores, this explanation is congruent with many studies [13,16,36-38], while disagrees with a study done by Degrazia, et al., who found that there was a significant difference between the control and Ag groups [15]. This may be due to the use of large Ag NPs size which interrupt the curing procedure and diminutions of the mechanical properties of the adhesive after adding the silver nanoparticles. The ZnO group had the highest value of the mean shear bond strength which was very close to the control group, and there was a very mild increase in SBS value of ZnO which was above the control group, this may be due to the use of this type of nanoparticles, which played an important role in increasing the chemical bonding to the resin matrix, this lets the more flexible matrix to transfer stresses to enamel surface, this fact coincide with other researchers and did not match with a study, who found that there was a significant difference between the control group and ZnO group, and this can be attributed to differences in the methodology involving the methods of evaluation of shear bond strength [14,17,39]. In addition, the present study also showed that the control group had a higher value of mean shear bond strength than TiO_2 group, this result may be due to compact consistency of the adhesive which may cause disturbance in the adhesive matrix, which interferes with the curing procedure and reduces the mechanical properties of the adhesive after adding the TiO_2 nanoparticles, this explanation is in agreement with Uysal, et al., and Poosti, et al., but they don't agree with Sodagar, et al., this can be attributed to the method of mixing where it was a manual mixing of nanoparticles with the adhesive at that research, not by a vortex, as in the current study [11,21,40].

Adhesive Remnant Index (ARI)

The ARI score was analyzed regarding the number and percentage amount of the adhesive remaining on the tooth surface. It ranged between 0 and 3 scores, it was one of the most frequently used indices in orthodontic adhesive testing, such index was used to determine the effect of adding nanoparticles (Ag, ZnO, and TiO_2) to the orthodontic adhesive system, regarding amount of the adhesive remaining on the tooth surface [11,13,21,40]. In this study, the predominant failure in control group was found in 9 specimens (75%), where there was no adhesive remained on the tooth surface (score 0), this could be due to the internal strength of this adhesive greater than the adhesion to the tooth surface [41], but the failure pattern expressed with less than 50% of adhesive remained on the tooth surface (score I) after incorporation of Ag nanoparticles in 7 specimens (58.33%), this may prevent the enamel from possible damage. However, the adhesive failure was between enamel and adhesive (there was no adhesive remained on tooth surface in the control group), this will increase the chance of harming the enamel tissue surface, this result can match with Degrazia, et al., this may be due to the large particle size of Ag nanoparticles which fuddles the deposition of adhesive into microporosity on the etched surface [15]. While after incorporating of ZnO nanoparticles, 8 specimens (66.66%) showed that less than 50% of adhesive remained on the teeth (score I), this result agreed with Sari, et al., this occurrence was due to a large particle size of ZnO nanoparticles which can cause deposition disturbances into micropores of the enamel surface [17]. When the TiO_2 was added to the orthodontic bonding agent, 6 specimens (50%) showed that more than 50% of adhesive remained on the tooth surface (score II) and 4 specimens (33.33%) where all the adhesive material remained on the tooth surface (score III), this result was with the line of results that was demonstrated by Poosti, et al., this fact was due to the usage of small particle size of TiO_2 which enhances its deposition into micropores in demineralized enamel [11]. In regard to comparison of ARI among different groups, there was a high significant difference between control group and ZnO, and TiO_2 groups. The adding of ZnO and TiO_2 nanoparticles to the primer increases the amount of adhesive deposition remained on the tooth surface after the incorporation, this findings disagreed with Uysal, et al., [40], who observed that there was no significant difference between the control group and the test groups regarding to ARI, this difference in result was due to the difference in methodology in which they use the ceramic bracket in their study, which was an important factor which affects ARI test, the result of our study showed, there was a significant difference between control and Ag groups, the adding of Ag nanoparticles to the primer increases the amount of adhesive deposition remained on the tooth surface after incorporation of nanoparticles leading to (score I), this findings disagreed with Blöcher, et al., who observed that there was no significant difference between the control group and Ag group, these differences with our result can be attributed to the low concentration of nanoparticles [13]. A less than 50% of the adhesive material remained on the tooth surface (score I) was the most common score in the Ag, ZnO groups, which is beneficial for time-saving purposes, this can agree with the results reported by other researchers [13,17,40], while more than 50% of the adhesive material remained on the tooth surface (score II), and it was the most common score in the TiO_2 group, which is beneficial for reducing the risk of enamel damage, and this result agreed with Proffit, et al., [42]. In regard to the benefit of low or high ARI scores, it has to be mentioned that the more adhesive left on the tooth leads to reduce the risk of enamel damage, which might be beneficial for the patient as reported by Katona [43]. Nevertheless, no adhesive remaining on the tooth surface (score I) appeared to be favorable because the chair time would be reduced [44].

After the bracket removal in TiO_2 group, more adhesive remains on the enamel surface if compared with less amount of adhesive which remained on the tooth surface in the other groups, can reduce the enamel damage after the debonding.

CONCLUSION

The incorporating of silver, zinc oxide or titanium dioxide nanoparticles into orthodontic bonding agent at a concentration (1%) has no effect on bond strength. All 3 type of nanoparticles has shear bond strength values above the minimum for clinical routine use. The results suggest significant differences in ARI, considerably more adhesive remains on the enamel surface following bracket removal in Ag, ZnO, and TiO_2 groups, if compared with less amount of adhesive which remained on the tooth surface in the control group, thus reducing the enamel damage, on the other hand increasing chair time in the removal of the adhesive remnants on enamel surface.

DECLARATIONS

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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