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Shear Bond Strength and Adhesive Remnant Index of Orthodontic Brackets Bonded To Enamel Using Orthodontic Primer Mixed With Silver Nanoparticles, Titanium Dioxide Nanoparticles, Hydroxyapatite and Chitosan Nanoparticles

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Abstract

Aim and Objectives: To evaluate and compare the shear bond strength (SBS) and adhesive remnant index (ARI) after incorporation of different nanoparticles to an orthodontic primer.

Materials and Methods: 100 extracted premolar teeth were divided into 5 groups on the basis of type of nanoparticle. Orthodontic primer (Orthosolo, Ormco) was mixed with 1% Silver nanoparticle, 1% Titanium dioxide nanoparticle, 1% Hydroxyapatite nanoparticle and 1% Chitosan nanoparticle. An Instron machine was used to assess the shear bond strength at a cross-head speed of 0.5 mm/min. The enamel surface was examined using a stereomicroscope with a 10X magnification.

Results: Group A (Control Group) shows maximum shear bond strength (8.59 + 5.53 MPa) whereas Group C (Primer incorporated with Titanium dioxide nanoparticle) shows minimum shear bond strength (5.21 + 3.93 MPa). Most of the groups (A, B, D and E) showed greater bond failure at composite-bracket interface except Group C which showed greater bond failure at enamel-composite interface.

Conclusion: No significant difference was observed between all the five groups in terms of shear bond strength. However, statistically significant difference was observed between all the five groups in terms of adhesive remnant index.

Keywords: Silver nanoparticle, Titanium dioxide nanoparticle, Hydroxyapatite nanoparticle, Chitosan nanoparticle, Shear bond strength.

Introduction

The most frequent side effects of fixed orthodontic therapy are white spot lesions. The dysbiotic dental biofilm brought on by poor oral hygiene during therapy and the persistence of tooth demineralization are the causes of these lesions. As a lesion develops, it could become a deep, uncleanable cavity.[1] It has been reported that demineralization of the enamel surrounding the brackets occurred in 50–70% of patients receiving fixed orthodontic treatment. The cervical borders of the teeth, the areas beneath the bands where the cementing media has been washed out, the resin surfaces next to bonded attachments and the point where the bonding resin and the etched enamel surfaces meet are the sites for such accumulation.[2]

While normal caries typically take at least six months to form, white spot lesions can be seen around the brackets as soon as one month after bracket placement. Demineralization is a serious clinical issue that can lead to an unsatisfactory cosmetic appearance and in extreme circumstances, the need for restorative care.[3] Many techniques, such as mouth rinses, toothpastes, and varnishes with fluoride, have been developed to reduce these biological effects.[4]

Researchers in dentistry have recently become more interested in nanomaterials or materials smaller than 100 nm, due to their special structures and characteristics, which include small size, high surface energy, big surface area, and a high percentage of surface atoms.[5] In order to decrease microbial adhesion and prevent caries, nanoparticles can be included into dental materials via two different mechanisms: coating them on the surface or mixing them with the material itself. They have been suggested for use in orthodontic treatment for a number of reasons, including preventing bacteria, decreasing friction and strengthening bonds.[6]

Because patients receiving fixed orthodontic appliance treatment have significantly higher levels of streptococcus mutans in their saliva and plaque, both bracket and bonding adhesive materials may retain plaque because this new site is more prone to caries. This increases the patient's risk of developing caries.[7] To stop microbial adherence or enamel demineralization during orthodontic therapy, nanoparticles can be placed on the surface of orthodontic appliances or added to orthodontic adhesive, primer, or cement. The high charge density of nanoparticle causes interaction with negatively charged surface of bacterial cells which results in antibacterial activity. Application of nanoparticles in devices have been reported to improve mechanical strength and efficiency of systems.[8] An adhesive and bonding primer are the two components of orthodontic composite bonding systems. The purpose of the primer is to ensure a proper bond strength between the tooth and bracket. An antimicrobial primer lowers biofilms and demineralizes the interface between the bracket and the tooth surface, which is advantageous for orthodontic bonding composite adhesives that are applied to the enamel surface after priming.[9] Hence a study was conducted to evaluate the shear bond strength of nanoparticle containing orthodontic primer.

Aim and Objectives: The aim of the study was to evaluate and compare the shear bond strength and adhesive remnant index after incorporation of silver, titanium dioxide, hydroxyapatite and chitosan nanoparticle to orthodontic primer.

Materials & Method:

Materials used for the study:

1. 100 extracted premolar teeth
2. 1% thymol
3. PVC pipe (diameter of 19mm X 24mm in height)
4. Self-cure acrylic resin (monomer and polymer)
5. Nanoparticles (1% Silver nanoparticle, 1%Titanium dioxide nanoparticle, 1% Hydroxyapatite nanoparticle, 1% Chitosan nanoparticle)
6. Vortex machine
7. Test tubes
8. Pumice
9. 37% phosphoric acid
10. Primer (Orthosolo, Ormco)
11. Adhesive (Enlight, Ormco)
12. Applicator tip
13. 022 MBT premolar brackets (Koden)
14. Bracket holding tweezer
15. Light cure gun (LED light, waldent)
16. Instron Universal testing machine
17. Stereo microscope (10X magnification)

Methodology

Sample preparation

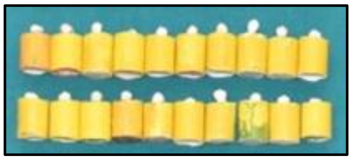
A total of 100 extracted premolar teeth were collected from the patients undergoing fixed orthodontic treatment. Teeth were cleared of debris and residual tissues and were then stored in 1% thymol solution till further use. Each extracted premolar tooth was mounted vertically in the block of Poly Vinyl Cyno-metha-acrylate (PVC) pipe (19mm X 24mm) with the help of self-cure resin such that the crown of the teeth was exposed above the cervical area for the purpose of bonding of bracket. The study being an in-vitro study patient consent and ethical approval was not required.

Grouping of the sample

All the samples were grouped into 5 groups and were colour coded according to the type of primer used (Group A (White), Group B (Black), Group C (Yellow), Group D (Red) and Group E (Blue)). Group A was the Control group (Orthosolo) whereas Group B, C, D and E were the study groups (Table 1).

Table 1: Color coded samples.

Group Name	Color Coding	Sample Prepared
Group A	White	
Group B	Black	

Group C	Yellow	
Group D	Red	
Group E	Blue	

Primer preparation

10mg of nanoparticle (Silver, Titanium dioxide, Hydroxyapatite and Chitosan) (Figure 1) was mixed uniformly with 1ml of Orthodontic primer (Orthosolo, Ormco) with the help of vortex mixer (Figure2).

Figure 1: Nanoparticles used for the study

Figure 2: Primer preparation with the help of vortex mixer (10mg of nanoparticle in 1ml of primer).

Bonding procedure

All five groups were etched with 37% phosphoric acid for 20 seconds, followed by a 15–20 seconds water rinsing and a thorough drying process using an air source devoid of moisture and oil to btain dull and frosty appearance. The etched enamel surface was then coated with a thin layer of orthodontic primer based on the type of group.

Group A- Primer (Orthosolo, Control group)

Group B- Primer with 1% Silver nanoparticle

Group C- Primer with 1% Titanium dioxide nanoparticle

Group D- Primer with 1% Hydroxyapatite nanoparticle

Group E- Primer with 1% Chitosan nanoparticle.

After that, a mild air burst for 1-2 seconds was used to thin the coating. The bracket surface was coated with a small layer of adhesive (Enlight, Ormco), which was then firmly pressed onto the buccal bond surface. Using a sharp scaler, the excess resin from the bracket edges was flushed out and an LED light emitting curing device was then used to irradiate the area for 20 seconds.

Measurement of shear bond strength

A Universal testing equipment was used to measure the shear bond strength. A chisel-shaped blade operating at a cross-head speed of 0.5mm/min applied a shearing force in Newtons vertically at the adhesion contact in the occluso-gingival direction until the bracket detached from the enamel surface (Figure 3). To convert the data into Megapascals (MPa), the force obtained was divided by the bracket surface area in mm^2 (11.05 mm^2).

Figure 3: Instron universal testing machine and measurement of shear bond strength.

Estimation of adhesive remnant index

Each tooth's enamel surface was examined under a stereomicroscope (10X magnification) to assess the quantity of adhesive left on the tooth surface following debonding. This was done using the modified adhesive remnant index (Olsen et al)[10].

Result

Shear Bond Strength Test

Normality test was conducted with the help of Shapiro Wilkinson test. Comparison of shear bond strength was evaluated with the help of one way ANOVA and Post hoc bonferroni test.

Out of 5 groups, Group A (Control Group) shows maximum shear bond strength (SBS) (8.59 ± 5.53 MPa) whereas Group C (Primer incorporated with Titanium dioxide nanoparticle) shows minimum shear bond strength (5.21 ± 3.93 MPa). Shear bond strength was observed in the following order: Group A- (Control group) (8.59 ± 5.53 MPa) > Group B- (Primer incorporated with Silver nanoparticle) (6.77 ± 4.15 MPa)> Group D- (Primer incorporated with Hydroxyapatite nanoparticle) (6.15 ± 2.97 MPa)> Group E- (Primer incorporated with Chitosan nanoparticle) (6.01 ± 3.36 MPa) > Group C- (Primer incorporated with Titanium dioxide nanoparticle) (5.21 ± 3.93 MPa) (Table 2). Out of 5 groups, 4 groups (Group A, B, D, E) had minimum acceptable SBS according to Reynolds[11] (5.9 to 7.8 Mpa) whereas group C had SBS (5.21 ± 3.93 MPa) which was below the acceptable SBS value.

Table 2: Comparison of shear bond strength between various groups.

Descriptive								
Shear Bond Strength								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval For Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Group A	20	8.59	5.533	1.237	6.01	11.18	2	20
Group B	20	6.77	4.152	.928	4.82	8.71	1	16
Group C	20	5.21	3.937	.880	3.36	7.05	1	14
Group D	20	6.15	2.975	.665	4.76	7.54	3	12
Group E	20	6.01	3.369	.753	4.43	7.58	2	13
Total	100	6.54	4.165	.416	5.72	7.37	1	20

One-way ANOVA did not report significant difference (p>0.05) between all groups (Table 3). Post hoc bonferroni test also reported no significant difference between any of pair group comparison (p>0.05) (Table 4).

Table 3: Comparison of shear bond strength using one-way ANOVA.

ANOVA					
Shear Bond Strength					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	129.882	4	32.471	1.943	.110
Within Groups	1587.344	95	16.709		
Total	1717.226	99			

Table 4: Post hoc test for multiple comparison.

Multiple Comparisons						
Dependent Variable: Shear Bond Strength						
Bonferroni						
(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Group A	Group B	1.830	1.293	1.000	-1.89	5.55
	Group C	3.390	1.293	.102	-.33	7.11
	Group D	2.445	1.293	.616	-1.27	6.16
	Group E	2.590	1.293	.480	-1.13	6.31
Group B	Group C	1.560	1.293	1.000	-2.16	5.28
	Group D	.615	1.293	1.000	-3.10	4.33
	Group E	.760	1.293	1.000	-2.96	4.48
Group C	Group D	-.945	1.293	1.000	-4.66	2.77
	Group E	-.800	1.293	1.000	-4.52	2.92
Group D	Group E	.145	1.293	1.000	-3.57	3.86

Adhesive Remnant Index

Comparison of adhesive remnant index was evaluated with the help of Chi square test.

In Group A, Group B, Group D and Group E greater bond failure was observed at composite-bracket interface with ARI Index of 1 (Group A (45%), B (50%), D (45%), E (45%)) whereas in Group C greater bond failure was observed at enamel-composite interface with an ARI Index of 4 Group C (40%).

Statistically significant difference was reported in Chi square test with respect to various ARI scores between the study groups (p<0.05) (Table 5).

Table 5: Comparison of ARI Index between different groups.

	1	2	3	4	5	Chi Square Test
Group A	9 (45%)	2(10%)	6 (30%)	2(10%)	1 (5%)	0.0001*
Group B	10(50%)	0	3(15%)	4(20%)	3(15%)	
Group C	5 (25%)	3 (15%)	3 (15%)	8 (40%)	1 (5%)	
Group D	9 (45%)	2 (10%)	2 (10%)	5 (25%)	2 (10%)	
Group E	9 (45%)	2 (10%)	4 (20%)	5 (25%)	0	

Discussion

Long-term treatment with fixed orthodontic appliances alters the normal oral environment, which increases the chance of pathogenic bacteria like Streptococcus mutans and lactobacilli. This can initiate a series of events that could eventually lead to decalcification and the development of caries. In order to encourage re-mineralization, many scientists are looking at the usage of fluoride in adhesives. Sadly, these additives' effects might only last a few weeks, which would increase the likelihood of adhesive failure. To make the most of the features of nanotechnology, other researchers have looked into adding metal nanoparticles to adhesives. Nevertheless, the incorporation of specific metal nanoparticles into orthodontic resin results in undesirable alterations to the color of enamel[12].

Moreover, the application of metal nanoparticles intensifies their cytotoxicity. More than 60% of the weight of the dentin is made up of the crystalline calcium phosphate complex hydroxyapatite, which makes up the majority of the enamel mineral structure. It also formed the human bone's mineral matrix. The release of calcium from the enamel surface is inhibited by hydroxyapatite particles when they enter the porosities of demineralized enamel, strengthening the tooth's resistance to caries[13]. One biopolymer that is created naturally is chitosan. It has been discovered that chitosan and its derivatives reduce fungui, Streptococcus mutans and Streptococcus Sanguinis[14].

Comparison of Shear bond strength

Except for Group C, all of the groups in the current investigation (Groups A, B, D, and E) demonstrated clinically acceptable SBS (5.9 to 7.8 MPa), as suggested by Reynolds[11], suggesting that all of the groups can withstand shear stress to a adequate level. The Control group (Group A) had the highest shear bond strength, whereas the Titanium dioxide nanoparticle group (Group C) showed the lowest shear bond strength. On the other hand, there was no statistically significant variation in shear bond strength between the groups. The physical characteristics of the study groups were unaffected by the addition of 1% nanoparticle. Premolars extracted for orthodontic purposes were included in our sample since they are readily available and the outcomes can be immediately applied to clinical settings.

Our results were in agreement with previous researchers such as Poosti M et al[15] in 2013, Chu SH et al[9] in 2017, Jowkar Z et al[5], Hailan SY et al[16] in 2018, Firouzmanesh M et al[17], El-Awady et al[18], Mohammed et al[12] in 2023 and disagreement with Akhavan A et al[19] in 2013, Reddy et al[20] in 2016, Eslamian L et al[21] in 2020 who reported significant difference between control group and nanoparticle incorporated study group. This difference could be due to difference in methodology involving the concentration of nanoparticle size and method of adding the nanoparticles.

Akhavan A et al.[19] state that by enhancing the adhesive layer's mechanical strength and providing structural support, nanoparticles enhance adherence at the interface between the restorative material and tooth structure. Stress-absorbing nanoparticles function as an elastic layer between dental composite and enamel. Consequently, the shear bond strength increases.

Comparison of Adhesive remnant index

The quantity and percentage of adhesive that is still present on the tooth surface were examined in relation to the ARI score. In every group, a statistically significant difference was noted. In Groups A, B, D, and E, the maximum failure pattern (Score-1) was seen with all the composite was still on the tooth surface, whereas in Group C, the maximum failure pattern (Score-4) was seen with less than 10% of the composite was remaining on the tooth surface. There is less chance of enamel damage when there is more adhesive remaining on the tooth's surface[22]. It is advantageous, if there is no adhesive left on the tooth surface because chair side time is decreased[23]. These findings were in disaggrement with Uysal et al[24], and Blocher et al[25] who found no discernible difference between control and nanoparticle group.

Conclusion

1. The incorporation of silver, titanium dioxide, hydroxyapatite and chitosan in orthodontic bonding agent at a concentration (1%) add no effect of shear bond strength.
2. Out of the 4 nanoparticles, only 1 nanoparticle (Titanium dioxide) had shear bond strength below the acceptable clinical value (Reynolds) (5.9 to 7.8 Mpa).
3. Significant difference was observed in terms of ARI between all groups.

Limitations of our study

To investigate the clinical performance and potential risks and benefits of adding nanoparticles for the purpose of lowering the occurrence of white spot lesions in patients receiving fixed orthodontic treatment, long-term clinical trials are required. These oughts to specify the ideal nanoparticle concentration, size and preparation method (addition to primer vs adhesive).

This study's outcomes were created in vitro. Consequently, to validate these results and offer clinical suggestions, investigations must be conducted in a clinical setting.

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