The Effect of Three Different Types of Nanoparticles on Shear Bond Strength of Orthodontic Brackets: An *In Vitro* Study

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Abstract

Objectives: To evaluate shear bond strength (SBS) of brackets coated with three different types of nanoparticles (titanium dioxide [TiO_2], zinc oxide [ZnO], silver oxide [AgO]) on all surfaces of the bracket or all except the base. **Method:** A sample of 140 brackets was divided into four groups. The control group had 20 uncoated brackets, whereas three experimental groups had 40 samples coated with different nanoparticles. These groups are further divided into two subgroups, A and B, one with coating on all surfaces as A and the other with coating on all surfaces except the base as B. The brackets were bonded to premolars and evaluated for SBS. Teeth surfaces were examined using a stereomicroscope and scored using the adhesive remnant index. **Results:** The study found that among all groups, brackets coated with TiO_2 nanoparticles on all surfaces showed the highest SBS, whereas brackets coated with ZnO nanoparticles on all surfaces showed the least bond strength. In intragroup comparison, brackets coated with TiO_2 nanoparticles on all surfaces showed a significant increase in SBS compared to the group coated with TiO_2 on all surfaces except the base. AgO and ZnO-coated groups showed no significant difference. **Conclusion:** In summary, TiO_2 nanoparticle-coated brackets showed the highest SBS, followed by the control group, AgO nanoparticle-coated brackets, and least by ZnO nanoparticle-coated brackets. However, they are within normal range.

Keywords: Nanoparticles, Orthodontic brackets, Shear bond strength.

Introduction

Orthodontic treatment is crucial for enhancing oral health and esthetics, but ensuring patient compliance is a significant challenge. During orthodontic therapy, it might be difficult for patients to practice good oral hygiene, which in turn leads to harboring various microorganisms. Because of this, many orthodontists employ alternate techniques that do not require patient compliance.[1]

Alternative methods have been employed to reduce the demineralization of enamel in patients who are wearing fixed orthodontic appliances. These methods include applying coatings and bonding agents to brackets and wires or remineralizing agents next to orthodontic appliances; however, their application is constrained.[2] With the emerging nanotechnology and the distinct characteristics exhibited by nanoparticles, claims were made to utilize this approach in orthodontic bonding. This embodiment of nanoparticles into other orthodontic materials has revealed promising support concerning antimicrobial and mechanical properties.[3]

Research available states that nanofillers can reduce enamel demineralization without changing the composite's physical characteristics. Without compromising the shear bond strength (SBS), researchers verified that experimental composites made of different nanoparticles, such as titanium dioxide (TiO_2), zinc oxide (ZnO), and silver oxide (AgO), provided excellent antibacterial characteristics. These nanoparticles added to dental composites also improved their mechanical qualities, including their microhardness, flexural strength, and modulus of elasticity.[4] They also showed bond strength values better than those of the nanoparticle-free controls. The literature has stated that different bonding techniques are required to verify the requirements of the typical SBS, which ranges from 5.9 to 7.8 MPa.[5]

The goal in the rapidly expanding field of nanotechnology is to eventually bring these innovations into therapeutic practice.[6]

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The current study was planned to evaluate the SBS of brackets coated with three different types of nanoparticles (TiO_2 ZnO, and AgO) on all surfaces of the bracket or all surfaces except the base, and assess the composite residues on bracket bases using the adhesive remnant index (ARI)

Materials and Methods

The present *in vitro* study assessed SBS of three brackets coated with three different types of nanoparticles, either on all surfaces or all surfaces except the base. This study was conducted in the Department of Orthodontics and Dentofacial Orthopedics, St. Joseph Dental College. Ethical committee clearance was obtained from the institutional ethical committee for the use of human samples in the study. (Ethical committee serial no: CEC/13/2021-22, Date: April 19, 2022).

A total sample consisting of 140 stainless steel orthodontic brackets was grouped into four groups, as Groups I, II, III, and IV, based on the type of nanoparticle coating. Group I, with a sample size of 20 brackets, is taken as the control group and comprises uncoated brackets bonded with conventional composite. The remaining three groups were taken as experimental groups (Group II, III, and IV) further divided into two subgroups each and color-coded using nail varnish, the one with nanoparticle coated on all surfaces of bracket bonded with conventional composite sub-grouped as A and the other with nanoparticles coated on all surfaces except the base of bracket, subgrouped as B.

Inclusion criteria

1. Premolars are therapeutically extracted for orthodontic purposes
2. Teeth that are anatomically and morphologically well-defined.

Exclusion criteria

1. Carious teeth
2. Fractured crowns
3. Teeth with fluorosis
4. Variations in the crown with enamel structural defects
5. Teeth with restoration
6. History of previous orthodontic bonding.

Sample preparation

- ARI: The tooth surfaces were focused using a stereomicroscope and were scored using ARI. The samples were examined after debonding and were scored based on the ARI by Årtun and Brobakken.[7]

Bonding procedure

The study involved cleaning the buccal surfaces of teeth, treating them with 37% phosphoric acid, and air drying them. The enamel was then etched to a chalky white appearance. Primer was applied, and the adhesive was dispensed onto a metal bracket. The bracket was placed 4 mm away from the tooth's occlusal surface, and the adhesive was cured for 20 s. The samples were used to assess SBS.

Evaluation of bond strength

Instron testing machine (ITM) was used to perform the debonding process.[8] It has two jaws positioned vertically. The lower jaw was fitted with the acrylic block that had the tooth inserted in it. The machine's upper jaw was versed with a stainless-steel chisel that had a tip of 1 mm. The jaws were positioned at the start of the testing so that the upper jaw's chisel would fit into the bracket's occlusal tie wing, which is glued to the tooth. The debonding forces operating between the jaws were shown on an electronic console that was connected to the INSTRON unit. Thus, using the electronic console, the precise force at which the bracket debonded was recorded in Newtons. The following formula was used to calculate the SBS in MPa based on the force value.[5]

$$\text{Shear bond strength (Mpa)} = \frac{\text{Force in networks}}{\text{Base area of the bracket (sq.mm)}}$$

Assessment of ARI

After the brackets had been removed, each tooth's enamel surface was inspected by trans-illumination of the buccal surface using a fiber optic light with a 10× magnification lens to analyze the quantity of adhesive still present on each tooth. The following scale was considered to record the ARI scores in accordance with Artun and Bergland's original description:

- 0 – Leaving the teeth free of adhesive
- 1 – The adhesive remains on the tooth is less than half
- 2 – The adhesive remains on the tooth by more than half
- 3 – The bracket mesh is clearly imprinted on the tooth, with all adhesive remaining.

A Scanning electron microscope (SEM) (ZEISS DSM 950, Germany) was used to study a few selected surfaces from each group in order to observe the enamel surface following debonding.

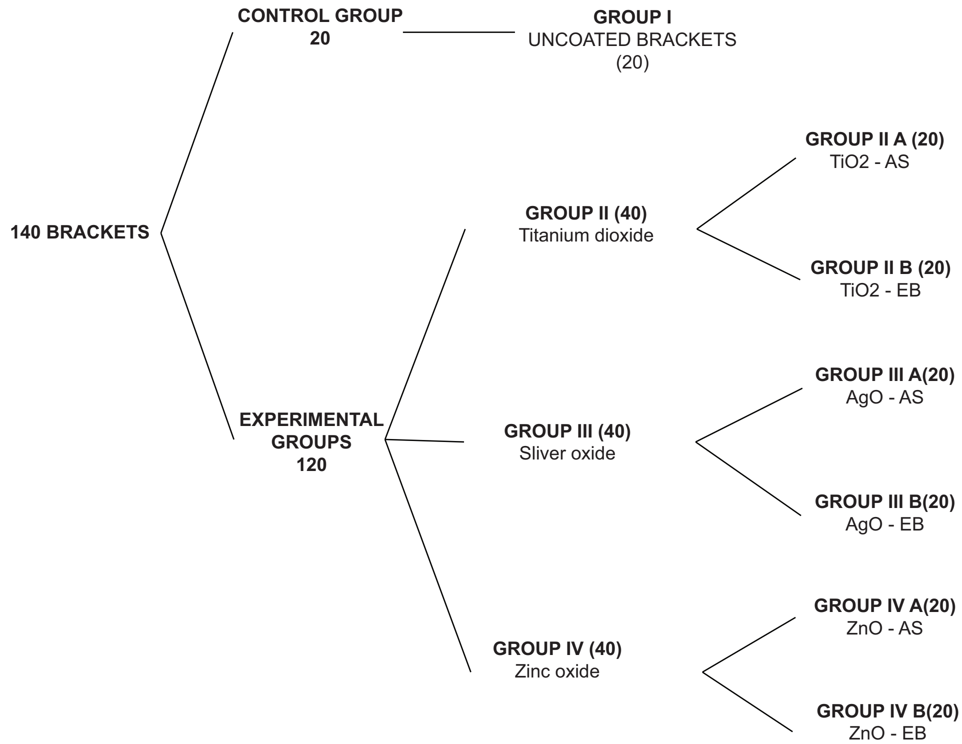
Results

Statistical analysis

Software used is IBM (Statistical Package for the Social Sciences version 27).

Based on the findings of the present study, the following results were noticed:

- Among all groups, brackets coated with TiO_2 nanoparticles on all surfaces (Group II A) showed the highest bond strength of 8.3 MPa followed by Group III B (brackets-coated with AgO nanoparticles on all surfaces except base) 6.6 MPa, Group I (uncoated brackets) 6.47 MPa, Group IV B (brackets coated with ZnO nanoparticles on all surfaces except base) 6.25 MPa, Group II B (orthodontic brackets coated with TiO_2 nanoparticles on all surfaces except base) 6.18 MPa, Group III A (orthodontic brackets coated with AgO nanoparticles on all surfaces) 5.74 MPa whereas brackets coated with ZnO nanoparticles on all surfaces (Group IV A) showed the least bond strength of 5.41 MPa.
- There is no statistically significant difference between the



control and any study groups except Group II A (TiO_2 nanoparticle coating on all surfaces), which showed a highly significant difference, whereas Group IV B (ZnO coating on all surfaces except base) showed the least SBS.

- In intragroup comparison, orthodontic brackets coated with TiO_2 nanoparticles on all surfaces (Group II A) showed a significant increase in bond strength compared to the orthodontic brackets coated with TiO_2 nanoparticles on all surfaces except the base (Group II B), which is statistically significant.
- On comparing the ARI scores among the groups, the Chi-square test revealed significantly ($P < 0.05$) different scores among the groups. In other terms, a higher ARI score of 2 and 3 is significantly seen in Group II A, whereas a lower ARI score of 0 and 1 is significantly seen in Group IV A.
- Group II A showed higher ARI scores of 2 and 3, which means that all or more part of the adhesive remained on tooth surfaces, indicating failure at the bracket-adhesive interface which shows increased SBS whereas for Group IV A most of the adhesive remained on the bracket (ARI scores of 0 and 1), indicating failure at the enamel-adhesive interface which shows decreased SBS.

Discussion

In this study, Table 1 shows a high statistical significance between the groups in SBS ($P < 0.001$). Among all groups, brackets coated with TiO_2 nanoparticles on all surfaces (Group II A) showed the highest SBS of 8.3 MPa followed by Group III B (brackets-coated with AgO nanoparticles on all surfaces except base) 6.6 MPa, Group I (uncoated brackets) 6.47 MPa, Group IV B (brackets coated with ZnO nanoparticles on all surfaces except base) 6.25 MPa, Group II B (orthodontic brackets coated with TiO_2 nanoparticles on all surfaces except base) 6.18 MPa, Group III A (orthodontic brackets coated with AgO nanoparticles on all surfaces) 5.74 MPa whereas brackets coated with ZnO nanoparticles on all surfaces (Group IV A) showed the least bond strength of 5.41 MPa.

Titanium coatings are often seen as ideal for bonding strength[9] due to their high strength and corrosion resistance. This might be the reason for the highest bond strength seen in brackets coated with TiO_2 nanoparticles on all surfaces, whereas the brackets coated with TiO_2 nanoparticles on all surfaces except the base showed no significant difference. In contrast, zinc and silver coatings are typically known to have properties of lower corrosion resistance and weaker bonding with adhesive, which in turn might be the cause for decreased bond strength in orthodontic brackets coated with ZnO and AgO nanoparticles.

In this study, Table 2 represents different nanoparticle-coated bracket groups compared to the control. It showed that only the brackets coated with TiO_2 nanoparticles on all surfaces (Group II A) showed a highly significant difference, whereas all other experimental groups showed no statistically significant difference when compared with the control group.

Reddy *et al*.[10] in their study found that adding 1% silver nanoparticles (AgNPs) to the orthodontic adhesive, i.e, TRANSBOND, significantly reduced SBS. SBS of the experimental adhesive was equally decreased by adding 0.11%, 0.18%, and 0.33% (w/w) of AgNPs to the orthodontic adhesive

Table 1: Intergroup comparison of SBS (MPa) using ANOVA test

Study groups	Mean	Standard deviation	Standard error	95% confidence interval for mean		Minimum	Maximum	F	*P*-value
				Lower bound	Upper bound				
Group I (control)	6.47	1.25	0.28	5.88	7.05	4.75	9.35	3.552	**<0.001****
Group II A (titanium dioxide – all surface)	8.36	2.8	0.66	6.69	9.47	2.50	13.21		
Group II B (titanium dioxide – except base)	6.18	1.55	0.35	5.45	6.90	3.97	8.10		
Group III A (silver oxide – all surface)	5.74	1.76	0.39	4.92	6.57	2.57	8.90		
Group III B (silver oxide – except base)	6.60	2.32	0.52	5.52	7.69	2.68	9.99		
Group IV A (zinc oxide – all surface)	5.41	1.98	0.44	4.48	6.33	1.97	9.20		
Group IV B (zinc oxide – except base)	6.25	1.88	0.42	5.36	7.13	3.86	9.65		

***P*<0.001: Highly significant, SBS: Shear bond strength, ANOVA: Analysis of variance

Table 2: Comparison of SBS (MPa) in each group with control using an independent paired *t*-test

Comparison groups		Mean difference	Standard error	*P*-value	95% confidence interval	
					Lower bound	Upper bound
Group I (control)	Group II A (titanium dioxide – all surface)	−1.89	0.62	0.047*	−3.53	0.30
	Group II B (titanium dioxide – except base)	0.29	0.64	1.00	−1.63	2.21
	Group III A (silver oxide – all surface)	0.73	0.64	0.92	−1.19	2.64
	Group III B (silver oxide – except base)	−0.13	0.64	1.00	−2.05	1.78
	Group IV A (zinc oxide – all surface)	1.06	0.64	0.65	−0.86	2.98
	Group IV B (zinc oxide – except base)	0.22	0.64	1.00	−1.70	2.14

SBS: Shear bond strength

Table 3: Intragroup pair-wise comparison of SBS (MPa) using paired *t*-test

Comparison groups		Mean difference	Standard error	*P*-value	95% confidence interval	
					Lower bound	Upper bound
Group II A (titanium dioxide – all surface)	Group II B (titanium dioxide – except base)	2.19	0.63	0.012*	−0.01	3.83
Group III A (silver oxide – all surface)	Group III B (silver oxide – except base)	−0.86	0.64	0.83	−2.78	1.06
Group IV A (zinc oxide – all surface)	Group IV B (zinc oxide – except base)	−0.84	0.64	0.85	−2.76	1.08

**P* < 0.05: Significant, SBS: Shear bond strength

(transbond) primer. Reduced SBS of the experimental adhesive containing AgNPs was also noted in another experiment conducted by Riad *et al*. The SBS of brackets coated with AgO on all surfaces or all surfaces but the base did not differ in the current investigation. The present study showed decreased SBS of brackets coated with AgO nanoparticles on all surfaces (Group III A), 5.74 MPa, and on all surfaces except the base (Group III B), 6.60 MPa, compared to Group II A and II B, but statistically significant compared to Group II A only. However, the SBS of AgO nanoparticle-coated brackets both in Group III A and III B were within the range of normal SBS of 5–9 MPa according to Kaio Sato *et al*.

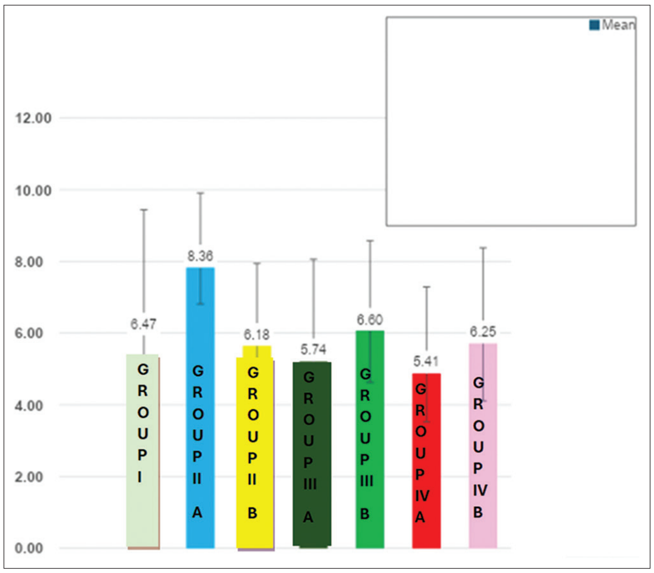
In this study, Table 3 shows an intragroup comparison of different groups. In this, orthodontic brackets coated with TiO_2 nanoparticles on all surfaces (Group II A) were highly statistically significant and showed the highest bond strength compared to the orthodontic brackets coated with TiO_2 nanoparticles on all surfaces except the base (Group II B). Group III A (AgO nanoparticle coating on all surfaces), when compared to Group III B (AgO nanoparticle coating on all surfaces except the base), showed decreased bond strength, but it was not statistically significant. Furthermore, Group IV A (ZnO nanoparticle coating on all surfaces), when compared to Group IV B (ZnO nanoparticle coating on all surfaces except bases), showed decreased bond strength; however, it was insignificant.

Spencer *et al*.[11] found that adding ZnO to Fuji Ortho LC, a light-cured resin-modified glass ionomer, did not affect the antibacterial properties or SBS. Higher amounts of ZnO were associated with greater antibacterial activity, and ZnO may help prevent decalcification associated with orthodontic treatment.[12] Hence, the present study included a group of brackets that are coated with ZnO nanoparticles on different surfaces and are evaluated to see its effect on bond strength. The present study showed similar results compared to their findings, but it is within the range of normal SBS.

Table 4: Distribution frequency and percentages of MARI scores using the Chi-square test

Study groups	MARI=0 (%)	MARI=1 (%)	MARI=2 (%)	MARI=3 (%)	*n*
Group I	4 (20)	5 (25)	5 (25)	6 (30)	20
Group II A	5 (25)	2 (10)	6 (30)	7 (35)	20
Group II B	3 (15)	6 (30)	7 (35)	4 (20)	20
Group III A	4 (20)	8 (40)	6 (30)	2 (10)	20
Group III B	3 (15)	5 (25)	6 (30)	6 (30)	20
Group IV A	6 (30)	8 (40)	3 (15)	3 (15)	20
Group IV B	7 (35)	3 (15)	3 (15)	7 (35)	20

Chi-square (χ^2)=18.16, Degree of freedom=9; P=0.0334, SBS: Shear bond strength



Graph 1: Intergroup comparison of shear bond strength (MPa)

In the present study, Table 4 shows the distribution frequency and percentage of ARI scores. The ARI is a commonly used method of assessing the quality of adhesion between the composite and the tooth, as well as between the composite and the bracket base. On comparing the ARI scores among the groups, the Chi-square test revealed significantly ($P < 0.05$) different scores among the groups. In other words, a higher ARI score of 2 and 3 is significantly seen in Group II A, whereas a lower ARI score of 0 and 1 is significantly seen in Group IV A.

Group II A showed higher ARI scores of 2 and 3, which means that all or more part of the adhesive remained on tooth surfaces, indicating failure at the bracket adhesive interface whereas for Group IV A most of the adhesive remained on the bracket (ARI scores of 0 and 1), indicating failure at the enamel-adhesive interface.

Graph 1 depicts that among all groups, orthodontic brackets coated with TiO_2 nanoparticles on all surfaces (Group II A) showed highest bond strength while Orthodontic brackets coated with ZnO nanoparticles on all surfaces showed least SBS (Group IV A) compared to the control i.e, Group I.

Limitations of the study

The current study offers valuable insights into the effects of nanoparticle coatings on orthodontic bracket bond strength, but it may have certain limitations that should be considered:

1. Small sample size
2. Short-term assessment
3. Assessing bond strength immediately after bonding might not capture how well the brackets hold up over time
4. Lack of diversity
5. Using a single type of nanoparticle may provide an explanation for potential interactions between different types, limiting the study's scope.

Future scope of the study

1. To experiment with different types and concentrations of nanoparticles to find an effective combination for enhancing bond strength
2. To explore alternative materials and surface treatments to know the potential for increasing bond strength without compromising safety
3. To investigate the durability of nanoparticle-coated brackets over time and how they withstand daily challenges such as chewing forces and exposure to acids in the mouth.

Conclusion

TiO_2 nanoparticle-coated brackets showed the highest SBS, followed by the control group, AgO nanoparticle-coated brackets, and least by ZnO nanoparticle-coated brackets. However, they are within the normal range.

Ethical Approval

Ethical committee clearance was obtained from the institutional ethical committee to use human samples in study. (Ethical committee serial no: CEC/13/2021-22, Date: 19/04/2022).

Informed Consent

All participants have consented to the submission of the article to the journal.

Declaration of Conflicting Interests

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

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References

1. Balenseifen JW, Madonia JV. Study of dental plaque in orthodontic patients. J Dent Res 1970;49:320-4.
2. Ewald A, Glückermann SK, Thull R, Gbureck U. Antimicrobial titanium/

silver PVD coatings on titanium. Biomed Eng Online 2006;5:22.
3. Borzabadi-Farahani A, Borzabadi E, Lynch E. Nanoparticles in orthodontics, a review of antimicrobial and anti-caries applications. Acta Odontol Scand 2014;72:413-7.
4. Riad M, Harhash AY, Elhiny OA, Salem GA. Evaluation of the shear bond strength of orthodontic adhesive system containing antimicrobial silver nano particles on bonding of metal brackets to enamel. Life Sci J 2015;12:27-34.
5. Reynolds IR, Von Fraunhofer JA. Direct bonding of orthodontic brackets--a comparative study of adhesives. Br J Orthod 1976;3:143-6.
6. Ozak ST, Ozkan P. Nanotechnology and dentistry. Eur J Dent 2013;7:145-51.
7. Årtun J, Brobakken BO. Prevalence of carious white spots after orthodontic treatment with multi bonded appliances. Eur J Orthod 1986;8:229-34.
8. Mojtahedzadeh F, Akhoundi MS, Noroozi H. Comparison of wire loop and shear blade as the 2 most common methods for testing orthodontic shear bond strength. Am J Orthod Dentofacial Orthop 2006;130:385-7.
9. Poosti M, Ramazanzadeh B, Zebarjad M, Javadzadeh P, Naderinasab M, Shakeri MT. Shear bond strength and antibacterial effects of orthodontic composite containing TiO_2 nanoparticles. Eur J Orthod 2013;35:676-9.
10. Reddy AK, Kambalyal PB, Patil SR, Vankhre M, Khan MY, Kumar TR. Comparative evaluation and influence on shear bond strength of incorporating silver, zinc oxide, and titanium dioxide nanoparticles in orthodontic adhesive. J Orthod Sci 2016;5:127-31.
11. Spencer CG, Campbell PM, Buschang PH, Cai J, Honeyman AL. Antimicrobial effects of zinc oxide in an orthodontic bonding agent. Angle Orthod 2009;79:317-22.
12. Jatania A, Shivalinga BM. An *in vitro* study to evaluate the effects of addition of zinc oxide to an orthodontic bonding agent. Eur J Dent 2014;8:112-7.