

Effect of Various Concentrations of Zirconia and Alumina Nanoparticles on Shear Bond Strength of Different Orthodontic Composites: An *In Vitro* Study

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Abstract

Objectives: The objective of this study was to evaluate the effect of various concentrations of Zirconia (ZrO₂) and Alumina (Al₂O₃) nanoparticles (NPs) incorporation on the shear bond strength (SBS) of the two different orthodontic composites. **Methods:** A total of 200 freshly extracted premolars were divided into two groups of 100 teeth each, based on the two composites. The extracted teeth in each of these two groups were further divided into five subgroups with ten teeth ($n = 10$) in each, for each NP depending on the concentrations of NPs (0.0%, 1.0%, 2.0%, 5.0%, and 10.0%) in the Orthofix and Enlight composites. Then, the teeth were mounted in cold-cure acrylic resin poured into PVC tubes. The teeth were vertically embedded in acrylic up to the cemento-enamel junction, and a standard bonding procedure was carried out to bond the brackets using both composites. The SBS was evaluated using a universal testing machine at a crosshead speed of 05 mm/min until the brackets de-bond from the tooth surface. The obtained data were subjected to statistical analysis using one-way analysis of variance (ANOVA) and *post hoc* tests. **Results:** The composites modified with 1.0 wt% ZrO₂ and Al₂O₃ NPs compared the control and other modified groups. One-way ANOVA showed significant differences ($P = 0.000$) among the groups. *Post hoc* analysis showed significant differences between the control and modified groups of composites except the Orthofix control group with 1.0 Wt% ZrO₂ and 1.0% and 2.0% of Al₂O₃ groups. The control group of Enlight showed significant differences with 5.0 and 10.0 wt% of both the NPs groups ($P = 0.000$). **Conclusion:** Both the composites modified with 1.0 wt% of ZrO₂ and Al₂O₃ NPs demonstrated more SBS compared to the unmodified and other modified groups.

Keywords: Alumina nanoparticles, Enlight, Orthofix, Shear bond strength, Zirconia.

INTRODUCTION

The field of orthodontics has long been dedicated to seeking dental materials that offer superior mechanical properties and enhanced clinical performance. One particularly promising avenue in this pursuit is the incorporation of nanoparticles (NPs) into orthodontic composites, a strategy with the potential to fortify the shear bond strength (SBS) of these materials, a critical determinant of the efficacy of orthodontic treatments.^[1-4] A secure bond between orthodontic brackets and enamel is essential for the success of orthodontic therapies, making SBS a pivotal factor in the durability and dependability of this bond.^[5,6] Elevating the SBS of orthodontic composites is essential to ensure the lasting attachment of orthodontic appliances to the teeth throughout the course of treatment.

The literature has previously documented the impact of introducing diverse NPs into orthodontic composites.^[5]

Positioned at the intersection of dental science and material engineering, it capitalizes on the distinctive features of NPs to intricately enhance the mechanical properties of these composites. The significance of NP modification in dental composites has been underscored by the quest for materials that can endure the rigorous mechanical demands of the oral environment.^[7] NP-reinforced composites are envisioned to offer improvements in strength, resilience, and clinical performance.^[5,7-9]

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Numerous studies reported the concentration of NPs on mechanical properties,^[1] adhesive qualities,^[5,8] and emphasized the need for optimizing NP concentration to achieve improved properties of resin composites.^[1,3,5] The type of NP also has an impact on SBS and mechanical properties of dental composites.^[5] The evidence from these studies underscores the multifaceted nature of NP modification in dental materials and its potential to redefine the field. In addition, the studies shed further light on the complex interactions between NPs and dental composites, as well as the comprehensive mechanical properties and systematic enhancement of SBS through NP incorporation.^[10-13]

The integration of Silver,^[14,15] Zinc Oxide,^[16] Titania,^[17,20] Zirconia (ZrO_2), and Alumina (Al_2O_3) NPs into dental materials has garnered significant attention due to their profound influence on mechanical properties. These NPs act as reinforcing agents, augmenting attributes such as strength, hardness, and wear resistance. Their capacity for meticulous adjustment enhances clinical performance, notably exemplified by heightened SBS in orthodontic composites.^[17-20] Furthermore, the potential of ZrO_2 and Al_2O_3 NPs to bolster fracture toughness and durability in dental restorative materials has been explored. However, there remains a scarcity of literature regarding the impact of ZrO_2 and Al_2O_3 NP integration on orthodontic composite properties. Thus, this study aimed to incorporate ZrO_2 and Al_2O_3 NPs and assess the SBS of orthodontic composites, Orthofix and Enlight.

MATERIALS AND METHODS

Two different composite materials, such as Orthofix (Manufacturer details) and Enlight (Ormco Corporation, USA), were used in this *in vitro* study and modified with various concentrations of ZrO_2 and Al_2O_3 NPs with an average particle size of 80–100 nm (Nanoresearch Lab, India).

Nanocomposites preparation

For the fabrication of composite containing different concentrations of ZrO_2 and Al_2O_3 NPs, 200 mg, 100 mg, 40 mg, and 20 mg of each NP powder was mixed with 1800 mg, 1900 mg, 1960 mg and 1980 mg of each of the composites such as Orthofix and Enlight composite, to obtain 2000 mg of the composites containing NPs with 10.0%, 5.0%, 2.0%, and 1.0% concentrations. The required amounts of composite and the NPs were blended using a composite mixer (High Energy Ball Mill, Retsch – Emax) at a speed of 3500 revolutions/min in a dark chamber for 5 min.

Specimen preparation and evaluation of SBS

Two hundred premolars, freshly extracted for orthodontic treatment purposes, were divided into two groups of 100 teeth each for two composites. One hundred teeth from each group were randomly divided into two subgroups with 50 each based on the NPs (ZrO_2 and Al_2O_3). A total of 10 extracted teeth ($n = 10$) were allocated to each concentration of two different NPs (0.0%, 1.0%, 2.0%, 5.0%, and 10.0%) in each composite material. The inclusion criteria for tooth selection were anatomically and morphologically well-defined extracted premolars with intact buccal enamel surfaces, and without any developmental defects, enamel caries, or fractured crowns.

Then, the samples were mounted in cold-cure acrylic resin poured into PVC tubes. The teeth were vertically embedded in acrylic up to the cemento-enamel junction, and a standard bonding procedure was carried out.

Buccal surfaces were cleaned with a prophylaxis brush without powder, rinsed, and dried. About 35% phosphoric acid (Ultra-Etch, Ultradent, USA) was administered for 30 s, followed by rinsing for 30 seconds and gentle air drying. After positioning the stainless-steel orthodontic brackets (Standard edgewise, 0.018-in slot, 12.62 mm² base area, Ormco Corporation, USA), a uniform, thin coating of adhesive (3M Unitek, USA) was applied to the buccal surfaces and light-cured (Woodpecker, UK) for 10 s. All specimens were stored in distilled water for 7 days before the evaluation of the SBS.

The SBS was measured using a universal testing machine (Model: AE-UTM-LC2, Advanced Equipments, India). The specimens were secured properly on the universal testing machine, and the bracket base was parallel to the direction of the applied force. Then, the shear load was applied at the bracket and the composite interface using a 0.6-mm metal blade in an incisogingival direction at a crosshead speed of 0.5 mm/min. The obtained debonding load (N) was divided by the bracket surface area (mm²) to calculate the SBS in megapascals.

The obtained data were subjected to statistical analysis using the Statistical Package for the Social Sciences, 21.0, NY, USA. The data were analyzed using one-way analysis of variance (ANOVA), followed by Tukey's *post hoc* test, used to find statistically significant differences between and within the groups. $P < 0.05$ was considered statistically significant, at a 95% confidence interval.

RESULTS

Orthofix composite modified with 1.0 wt% of ZrO_2 (13.5630 ± 1.74797 MPa) and Al_2O_3 (14.0060 ± 1.74149 MPa) NPs showed more SBS followed by the unmodified groups. An increase in the NP concentration reduced the SBS of the Orthofix composite. One-way ANOVA demonstrated a significant difference ($P = 0.000$) among the groups (Table 1).

Enlight composite behaved similarly to the Orthofix composite. Enlight modified with 1.0 wt% of ZrO_2 (19.9250 ± 3.26975 MPa) and Al_2O_3 (20.3130 ± 3.10156 MPa) NPs demonstrated more SBS followed by the control groups. Enlight composite modified with 2.0, 5.0, and 10 Wt% of NPs showed a gradual decrease in the SBS and their SBS is less than the control groups. One-way ANOVA exhibited a significant difference ($P = 0.000$) among the groups (Table 2).

Among the two composite materials, Enlight displayed more SBS compared to the Orthofix at different concentrations of NPs (Figure 1). One-way ANOVA demonstrated significant differences between the two composites at 0.00 wt% (control) ($P = 0.006$), 2.0 wt of ZrO_2 ($P = 0.002$), and Al_2O_3 (0.002) NPs.

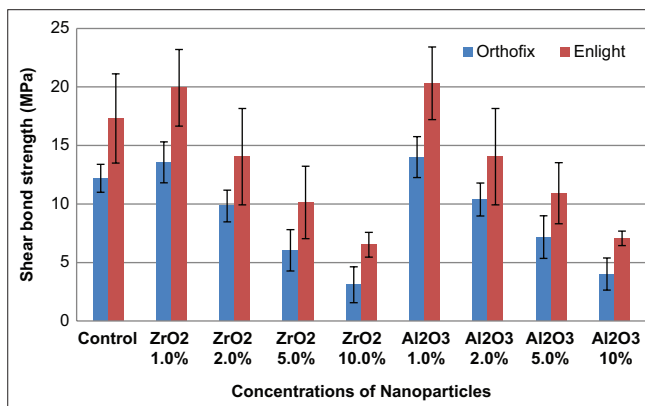
In *post hoc* analysis, the Orthofix control group exhibited significant differences with the modified groups of ZrO_2 NPs

Table 1: Comparison of SBS (MPa) of Orthofix modified with different concentrations of ZrO₂ and Al₂O₃ NPs (one-way ANOVA)

Groups	N	Mean	Std. deviation	Standard error	95% confidence interval for mean		Minimum	Maximum	Significance (P-value)
					Lower bound	Upper bound			
Control	10	12.1920	1.19984	0.37942	11.3337	13.0503	10.25	14.03	0.000
ZrO ₂ 1.0%	10	13.5630	1.74797	0.55276	12.3126	14.8134	11.17	16.35	
ZrO ₂ 2.0%	10	9.8340	1.35430	0.42827	8.8652	10.8028	7.72	12.27	
ZrO ₂ 5.0%	10	6.0450	1.76528	0.55823	4.7822	7.3078	3.27	9.21	
ZrO ₂ 10%	10	3.0990	1.53121	0.48421	2.0036	4.1944	1.25	5.71	
Al ₂ O ₃ 1.0%	10	14.0060	1.74149	0.55071	12.7602	15.2518	10.70	16.62	
Al ₂ O ₃ 2.0%	10	10.3830	1.41429	0.44724	9.3713	11.3947	7.44	12.04	
Al ₂ O ₃ 5.0%	10	7.1710	1.82113	0.57589	5.8682	8.4738	4.71	9.96	
Al ₂ O ₃ 10%	10	4.0110	1.36808	0.43263	3.0323	4.9897	2.27	6.57	

SBS: Shear bond strength, ZrO₂: Zirconia, Al₂O₃: Alumina, NPs: Nanoparticles, ANOVA: Analysis of variance**Table 2: Comparison of SBS (MPa) of Enlight modified with different concentrations of ZrO₂ and Al₂O₃ NPs (one-way ANOVA)**

Groups	N	Mean	Standard deviation	Standard error	95% confidence interval for mean		Minimum	Maximum	Significance (P-value)
					Lower bound	Upper bound			
Control	10	17.3110	3.80916	1.20456	14.5861	20.0359	11.74	24.57	0.000
ZrO ₂ 1.0%	10	19.9250	3.26975	1.03399	17.5860	22.2640	14.12	24.04	
ZrO ₂ 2.0%	10	14.0420	4.11522	1.30135	11.0981	16.9859	8.83	20.24	
ZrO ₂ 5.0%	10	10.1270	3.08888	0.97679	7.9173	12.3367	6.24	14.64	
ZrO ₂ 10%	10	6.5170	1.05738	0.33437	5.7606	7.2734	5.25	8.83	
Al ₂ O ₃ 1.0%	10	20.3130	3.10156	0.98080	18.0943	22.5317	15.25	25.17	
Al ₂ O ₃ 2.0%	10	14.0420	4.11522	1.30135	11.0981	16.9859	8.83	20.24	
Al ₂ O ₃ 5.0%	10	10.9240	2.61237	0.82610	9.0552	12.7928	7.41	16.11	
Al ₂ O ₃ 10%	10	7.0650	0.62108	0.19640	6.6207	7.5093	5.73	7.86	

SBS: Shear bond strength, ZrO₂: Zirconia, Al₂O₃: Alumina, NPs: Nanoparticles, ANOVA: Analysis of variance**Figure 1:** Shear bond strength of Orthofix and Enlight composites modified with different concentrations of Zirconia and Alumina nanoparticles

except with the 1.0 Wt% group and 1.0% and 2.0% of Al₂O₃ groups. Orthofix modified with 5.0 and 10 Wt% of Al₂O₃ NPs showed significant differences with the control groups (Table 3). Among the modified groups, significant differences were observed between the different concentrations of ZrO₂ NPs groups of Orthofix. Similarly, Al₂O₃ NPs modified groups of Orthofix demonstrated significant differences between different concentrations (Table 3). Intergroup comparison between the different concentrations of NPs, Orthofix modified with 1.0 wt% of ZrO₂ NPs showed significant differences with

2.0, 5.0, and 10.0 wt% of Al₂O₃ modified groups ($P = 0.001$, $P = 0.000$, and $P = 0.000$, respectively). Orthofix modified with 2.0 wt% of ZrO₂ showed significant differences with 10.0 wt% Al₂O₃ groups ($P = 0.000$, $P = 0.008$, and $P = 0.000$, respectively). Orthofix modified with 5.0 wt% of ZrO₂ displayed significant differences with 1.0 and 2.0 wt% of Al₂O₃ groups ($P = 0.000$). Orthofix modified with 10.0 wt% of ZrO₂ displayed significant differences with 1.0, 2.0, and 5.0 wt% of Al₂O₃ NPs groups (Table 3).

In *post hoc* analysis, control group of Enlight showed significant differences with 5.0 and 10.0 wt% of both the NPs groups ($P = 0.000$) (Table 4). Among the Al₂O₃ modified Enlight groups, significant differences were observed between the different concentrations of Al₂O₃ modified groups, except with the 5.0 wt% Al₂O₃ modified group, which did not show significant differences with 2.0 and 10.0 wt% Al₂O₃ modified group (Table 4). Enlight modified with 1.0 wt% of ZrO₂ NPs showed significant differences with 2.0, 5.0, and 10.0 wt% of Al₂O₃ modified groups ($P = 0.001$, $P = 0.000$, and $P = 0.000$, respectively). Enlight modified with 2.0 wt% and 10.0 Wt% of ZrO₂ showed significant differences with and 1.0, and 10.0 wt% Al₂O₃ groups (Table 4).

DISCUSSION

Incorporating NPs to modify the SBS of orthodontic composites is of paramount importance in the field of dental materials. These

Table 3: Post hoc analysis of SBS of Orthofix modified with different concentrations of ZrO₂ and Al₂O₃ NPs

Groups	Mean difference (I-J)	Standard error	significance	95% confidence interval	
				Lower bound	Upper bound
Control					
ZrO ₂ 1.0%	1.37100	0.69938	0.575	3.6001	0.8581
ZrO ₂ 2.0%	2.35800*	0.69938	0.030	0.1289	4.5871
ZrO ₂ 5.0%	6.14700*	0.69938	0.000	3.9179	8.3761
ZrO ₂ 10%	9.09300*	0.69938	0.000	6.8639	11.3221
Al ₂ O ₃ 1.0%	1.81400	0.69938	0.206	4.0431	0.4151
Al ₂ O ₃ 2.0%	1.80900	0.69938	0.209	0.4201	4.0381
Al ₂ O ₃ 5.0%	5.02100*	0.69938	0.000	2.7919	7.2501
Al ₂ O ₃ 10%	8.18100*	0.69938	0.000	5.9519	10.4101
ZrO ₂ 1.0%					
ZrO ₂ 2.0%	3.72900*	0.69938	0.000	1.4999	5.9581
ZrO ₂ 5.0%	7.51800*	0.69938	0.000	5.2889	9.7471
ZrO ₂ 10%	10.46400*	0.69938	0.000	8.2349	12.6931
Al ₂ O ₃ 1.0%	0.44300	0.69938	0.999	2.6721	1.7861
Al ₂ O ₃ 2.0%	3.18000*	0.69938	0.001	0.9509	5.4091
Al ₂ O ₃ 5.0%	6.39200*	0.69938	0.000	4.1629	8.6211
Al ₂ O ₃ 10%	9.55200*	0.69938	0.000	7.3229	11.7811
ZrO ₂ 2.0%					
ZrO ₂ 5.0%	3.78900*	0.69938	0.000	1.5599	6.0181
ZrO ₂ 10%	6.73500*	0.69938	0.000	4.5059	8.9641
Al ₂ O ₃ 1.0%	4.17200*	0.69938	0.000	6.4011	-1.9429
Al ₂ O ₃ 2.0%	0.54900	0.69938	0.997	2.7781	1.6801
Al ₂ O ₃ 5.0%	2.66300*	0.69938	0.008	0.4339	4.8921
Al ₂ O ₃ 10%	5.82300*	0.69938	0.000	3.5939	8.0521
ZrO ₂ 5.0%					
ZrO ₂ 10%	2.94600*	0.69938	0.002	0.7169	5.1751
Al ₂ O ₃ 1.0%	7.96100*	0.69938	0.000	10.1901	-5.7319
Al ₂ O ₃ 2.0%	4.33800*	0.69938	0.000	6.5671	-2.1089
Al ₂ O ₃ 5.0%	1.12600	0.69938	0.797	3.3551	1.1031
Al ₂ O ₃ 10%	2.03400	0.69938	0.102	0.1951	4.2631
ZrO ₂ 10%					
Al ₂ O ₃ 1.0%	10.90700*	0.69938	0.000	13.1361	-8.6779
Al ₂ O ₃ 2.0%	7.28400*	0.69938	0.000	9.5131	-5.0549
Al ₂ O ₃ 5.0%	4.07200*	0.69938	0.000	6.3011	-1.8429
Al ₂ O ₃ 10%	0.91200	0.69938	0.927	3.1411	1.3171
Al ₂ O ₃ 1.0%					
Al ₂ O ₃ 2%	3.62300*	0.69938	0.000	1.3939	5.8521
Al ₂ O ₃ 5%	6.83500*	0.69938	0.000	4.6059	9.0641
Al ₂ O ₃ 10%	9.99500*	0.69938	0.000	7.7659	12.2241
Al ₂ O ₃ 2.0%					
Al ₂ O ₃ 5.0%	3.21200*	0.69938	0.001	0.9829	5.4411
Al ₂ O ₃ 10%	6.37200*	0.69938	0.000	4.1429	8.6011
Al ₂ O ₃ 5.0%					
Al ₂ O ₃ 10%	3.16000*	0.69938	0.001	0.9309	5.3891

SBS: Shear bond strength, ZrO₂: Zirconia, Al₂O₃: Alumina, NPs: Nanoparticles, ANOVA: Analysis of variance

modifications aim to enhance the adhesive properties of these composites, ultimately improving their clinical performance in orthodontic applications. The incorporation of NPs offers the potential to fine-tune the mechanical properties of composites,

Table 4: Post hoc analysis of SBS of Enlight modified with different concentrations of ZrO₂ and Al₂O₃ NPs

Groups	Mean difference (I-J)	Standard error	significance	95% confidence interval	
				Lower bound	Upper bound
Control					
ZrO ₂ 1.0%	-2.61400	1.38692	0.626	7.0344	1.8064
ZrO ₂ 2.0%	3.26900	1.38692	0.322	1.1514	7.6894
ZrO ₂ 5.0%	7.18400*	1.38692	0.000	2.7636	11.6044
ZrO ₂ 10%	10.79400*	1.38692	0.000	6.3736	15.2144
Al ₂ O ₃ 1.0%	3.00200	1.38692	0.438	7.4224	1.4184
Al ₂ O ₃ 2.0%	3.26900	1.38692	0.322	1.1514	7.6894
Al ₂ O ₃ 5.0%	6.38700*	1.38692	0.000	1.9666	10.8074
Al ₂ O ₃ 10%	10.24600*	1.38692	0.000	5.8256	14.6664
ZrO ₂ 1.0%					
ZrO ₂ 2.0%	5.88300*	1.38692	0.002	1.4626	10.3034
ZrO ₂ 5.0%	9.79800*	1.38692	0.000	5.3776	14.2184
ZrO ₂ 10%	13.40800*	1.38692	0.000	8.9876	17.8284
Al ₂ O ₃ 1.0%	0.38800	1.38692	1.000	4.8084	4.0324
Al ₂ O ₃ 2.0%	5.88300*	1.38692	0.002	1.4626	10.3034
Al ₂ O ₃ 5.0%	9.00100*	1.38692	0.000	4.5806	13.4214
Al ₂ O ₃ 10%	12.86000*	1.38692	0.000	8.4396	17.2804
ZrO ₂ 2.0%					
ZrO ₂ 5.0%	3.91500	1.38692	0.125	0.5054	8.3354
ZrO ₂ 10%	7.52500*	1.38692	0.000	3.1046	11.9454
Al ₂ O ₃ 1.0%	6.27100*	1.38692	0.001	10.6914	1.8506
Al ₂ O ₃ 2.0%	0.00000	1.38692	1.000	4.4204	4.4204
Al ₂ O ₃ 5.0%	3.11800	1.38692	0.386	1.3024	7.5384
Al ₂ O ₃ 10%	6.97700*	1.38692	0.000	2.5566	11.3974
ZrO ₂ 5.0%					
ZrO ₂ 10%	3.61000	1.38692	0.202	0.8104	8.0304
Al ₂ O ₃ 1.0%	10.18600*	1.38692	0.000	14.6064	5.7656
Al ₂ O ₃ 2.0%	3.91500	1.38692	0.125	8.3354	0.5054
Al ₂ O ₃ 5.0%	0.79700	1.38692	1.000	5.2174	3.6234
Al ₂ O ₃ 10%	3.06200	1.38692	0.411	1.3584	7.4824
ZrO ₂ 10%					
Al ₂ O ₃ 1.0%	13.79600*	1.38692	0.000	18.2164	9.3756
Al ₂ O ₃ 2.0%	7.52500*	1.38692	0.000	11.9454	3.1046
Al ₂ O ₃ 5.0%	4.40700	1.38692	0.051	8.8274	0.0134
Al ₂ O ₃ 10%	0.54800	1.38692	1.000	4.9684	3.8724
Al ₂ O ₃ 1.0%					
Al ₂ O ₃ 2.0%	6.27100*	1.38692	0.001	1.8506	10.6914
Al ₂ O ₃ 5.0%	9.38900*	1.38692	0.000	4.9686	13.8094
Al ₂ O ₃ 10%	13.24800*	1.38692	0.000	8.8276	17.6684
Al ₂ O ₃ 2.0%					
Al ₂ O ₃ 5.0%	3.11800	1.38692	0.386	1.3024	7.5384
Al ₂ O ₃ 10%	6.97700*	1.38692	0.000	2.5566	11.3974
Al ₂ O ₃ 5.0%					
Al ₂ O ₃ 10%	3.85900	1.38692	0.137	0.5614	8.2794

SBS: Shear bond strength, ZrO₂: Zirconia, Al₂O₃: Alumina, NPs: Nanoparticles, ANOVA: Analysis of variance

leading to increased bond strength between orthodontic brackets and enamel. Research in this area, supported by studies,^[1,6] as well as other investigations, demonstrates the significant impact of NP type and concentration on SBS.^[3-5,21]

These findings underscore the need for tailored approaches to composite formulation for optimal clinical outcomes. The SBS of orthodontic composites, such as Orthofix and Enlight, modified with various concentrations of ZrO_2 and Al_2O_3 NPs was investigated in the present study and the results indicate several important findings.

The results of the present study showed that, in both Orthofix and Enlight composites, the addition of 1.0 wt% of ZrO_2 and Al_2O_3 NPs resulted in the highest SBS values compared to the control groups. This is consistent with the previous research findings that a moderate NP concentration can enhance the mechanical properties of composites.^[17] However, increasing the NP concentration to 2.0, 5.0, and 10.0 wt% led to a gradual decrease in SBS. This trend may be attributed to agglomeration of NPs at higher concentrations, reducing their reinforcing effect.^[14] The particle size and shape significantly impact SBS in polymer-based materials. As NP concentration increases, agglomeration occurs due to interparticle interactions, leading to reduced SBS. This may be attributed to agglomerated NPs enlarging in size and possibly creating stress-concentrating voids that promote crack propagation under stress.^[14,22] Larger particles were found to be less cytotoxic than smaller ones.^[18] Although the NPs used here were initially 80–100 nm in size, agglomeration likely increased their size.

Interestingly, Enlight composites consistently displayed higher SBS values compared to Orthofix, particularly at the 1.0 wt% NP concentration. This could be attributed to differences in the resin matrix or the dispersion of NPs within the two composite materials. The previous studies have noted that variations in resin chemistry can significantly impact the mechanical properties of composites.^[2,14]

The statistical analysis conducted through one-way ANOVA tests confirms the significance of the observed differences. Both Orthofix and Enlight composites exhibited statistically significant differences in SBS among various NP concentrations. This reinforces the impact of NP concentration on SBS. Within each composite, Orthofix and Enlight, the results demonstrate significant differences in SBS between different concentrations of ZrO_2 and Al_2O_3 NPs. This suggests that the specific type and concentration of NPs play a crucial role in determining SBS. The interactions between NPs and Orthodontic composites are multifaceted. The NPs, when incorporated, enhance mechanical properties, including SBS. Their surface chemistry facilitates adhesion to the composite matrix, reinforcing it. In addition, the fine dispersion of NPs may reduce agglomeration and void formation, promoting uniform mechanical enhancement. This integration is pivotal for augmenting the durability of orthodontic appliances. However, optimizing the concentration and dispersion of NPs is essential to harness their full potential and prevent potential drawbacks such as agglomeration.^[14,22] The results of this study also revealed that for both composites, 1.0 wt% of NPs consistently exhibited the highest SBS, while other concentrations, especially at the higher end, showed a decline.

Notably, the comparison of ZrO_2 and Al_2O_3 NPs within each composite material revealed different trends. For instance, Orthofix modified with 1.0 wt% of ZrO_2 NPs exhibited significant differences when compared to other ZrO_2 concentrations as well as Al_2O_3 concentrations. This demonstrates that not only the concentration but also the type of NPs can influence SBS. It is interesting to note that in some cases, certain composite groups did not display significant differences in SBS when compared to specific NP concentrations. For instance, Enlight modified with 5.0 wt% of ZrO_2 did not show significant differences when compared to 10.0 wt% ZrO_2 and Al_2O_3 modified groups. Such observations may suggest a threshold beyond which the influence of NPs on SBS becomes saturated.^[6]

As per Reynolds,^[23] the “clinically acceptable range for SBS falls within 6 to 8 MPa.” Our study indicated that the mean SBS of the modified groups exceeded this clinically acceptable range, with the exception being the inclusion of 10 wt% of ZrO_2 and Al_2O_3 NPs in Orthofix. These findings align with the previous studies conducted by Mahendra *et al.*^[19] and Reddy *et al.*^[16]

The results of this study demonstrated that the addition of NPs, particularly at a concentration of 1.0 wt%, can enhance the SBS of orthodontic composites. However, there is a diminishing return with increasing NP concentration. Enlight composites consistently exhibited higher SBS values compared to Orthofix, and the specific type and concentration of NPs significantly influenced SBS. Further, research may be needed to explore the long-term durability and clinical applicability of these modified composites.

CONCLUSION

The incorporation of NPs, ZrO_2 and Al_2O_3 , to modify the SBS of orthodontic composites is a pivotal endeavor with clinical implications. This study revealed that a delicate balance exists, where a 1.0 wt% concentration of these NPs substantially enhances SBS, while higher concentrations tend to diminish the adhesive properties. This underscores the need for precision when formulating orthodontic composites to achieve optimal SBS. Moreover, the comparative analysis of two composite materials, Orthofix and Enlight, demonstrated that the resin matrix and dispersion of NPs significantly influence SBS. Enlight consistently exhibited superior SBS, particularly at the 1.0 wt% NP concentration, highlighting the nuanced interplay of material composition and NP integration. The findings of this study align with existing research, emphasizing the profound impact of NP type and concentration on SBS. It is evident that nanomaterials have the potential to revolutionize orthodontic treatments, but meticulous customization is imperative.

These insights contribute to a deeper understanding of the intricate relationship between NPs and orthodontic composites, paving the way for the development of advanced materials that can better withstand orthodontic forces and enhance clinical outcomes. Further, investigations and long-term clinical trials

are warranted to establish the practical utility of NP-modified composites in orthodontic practice.

REFERENCES

1. Azmy E, Al-Kholy MR, Fattouh M, Kenawi LM, Helal MA. Impact of nanoparticles additions on the strength of dental composite resin. *Int J Biomater* 2022;2022:1165431.
2. Toodehzaeim MH, Zandi H, Meshkani H, Firouzabadi AH. The effect of CuO nanoparticles on antimicrobial effects and shear bond strength of orthodontic adhesives. *J Dent (Shiraz)* 2018;19:1-5.
3. Pourhajibagher M, Sodagar A, Bahador A. An *in vitro* evaluation of the effects of nanoparticles on shear bond strength and antimicrobial properties of orthodontic adhesives: A systematic review and meta-analysis study. *Int Orthodont* 2020;18:203-13.
4. Poosti M, Ramazanzadeh B, Zebarjad M, Javadzadeh P, Naderinasab M, Shakeri MT. Shear bond strength and antibacterial effects of orthodontic composite containing TiO₂ nanoparticles. *Eur J Orthodont* 2013;35:676-9.
5. Ahmed MK, Alsaleem NR, AlSamak S. The effect of vanillin nanoparticles on antimicrobial and mechanical properties of an orthodontic adhesive. *J Orthodont Sci* 2023;12:46.
6. Elfakhri F, Alkahtani R, Li C, Khaliq J. Influence of filler characteristics on the performance of dental composites: A comprehensive review. *Ceram Int* 2022;48:27280-94.
7. Xia Y, Zhang F, Xie H, Gu N. Nanoparticle-reinforced resin-based dental composites. *J Dent* 2008;36:450-5.
8. Behnaz M, Dalaie K, Mirmohammadsadeghi H, Salehi H, Rakhshan V, Aslani F. Shear bond strength and adhesive remnant index of orthodontic brackets bonded to enamel using adhesive systems mixed with TiO₂ nanoparticles. *Dent Press J Orthodont* 2018;23:43e1-7.
9. Cramer NB, Stansbury JW, Bowman CN. Recent advances and developments in composite dental restorative materials. *J Dent Res* 2011;90:402-16.
10. Gronwald B, Kozłowska L, Kijak K, Lietz-Kijak D, Skomro P, Gronwald K, *et al.* Nanoparticles in dentistry-current literature review. *Coatings* 2023;13:102.
11. He Y, Zhang Z, Zhang Z, Bai Y, Lin H, Shen, M. Nanoparticle reinforcement of dental resin composites. *J Dent Res* 2017;96:405-11.
12. Sharma A, *et al.* Effect of nanoparticle addition on the shear bond strength of orthodontic brackets. *J Orthodont Sci* 2016;5:10-4.
13. Zhang Z, Qian Y, Ji Z, Ma S, Wang Z, Yang X. The influence of nanoparticles on the shear bond strength of orthodontic brackets to enamel. *Eur J Orthodont* 2018;40:170-6.
14. Alla R, Swamy K, Vyas R, Konakanchi A, Guduri V, Gadde P. Influence of silver nanoparticles incorporation on flexural strength of heat-cure acrylic denture base resin materials. *Ann Res Rev Biol* 2017;17:1-8.
15. Alla RK, Guduri V, Tiruveedula NB, Rao GN, Raghavendra Swamy KN, Vyas R. Effect of silver nanoparticles incorporation on microhardness of Heat-cure denture base resins. *Int J Dent Mater* 2020;2:103-10.
16. 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.
17. Duvvuri SR, Arafath MM, Alla RK, Bhaskar V, Kumaran K. Evaluation of the shear bond strength of the orthodontic composites modified with various concentrations of TiO₂ nanoparticles: An *in vitro* study. *Uttar Pradesh J Zool* 2023;44:88-94.
18. Mansoor A, Khurshid Z, Khan MT, Mansoor E, Butt FA, Jamal A, *et al.* Medical and dental applications of titania nanoparticles: An overview. *Nanomaterials* 2022;12:3670.
19. Mahendra TV, Muddada V, Gorantla S, Karri T, Mulakala V, Prasad R, *et al.* Evaluation of antibacterial properties and shear bond strength of orthodontic composites containing silver nanoparticles, titanium dioxide nanoparticles and fluoride: An *in vitro* study. *Dent Press J Orthod* 2022;27:e222067.
20. Sodagar A, Akhouni MS, Bahador A, Jalali YF, Behzadi Z, Elhaminejad F, *et al.* Effect of TiO₂ nanoparticles incorporation on antibacterial properties and shear bond strength of dental composite used in orthodontics. *Dental Press J Orthod* 2017;22:67-74.
21. Gupta S, Ahluwalia R, Bindra PK, Chugh T. Nanotechnology in orthodontics: A detailed review. *J Surv Fisher Sci* 2023;10:970-5.
22. Akhavan A, Sodagar A, Mojtahedzadeh F, Sodagar K. Investigating the effect of incorporating nanosilver/nanohydroxyapatite particles on the shear bond strength of orthodontic adhesives. *Acta Odontol Scand* 2013;71:1038-42.
23. Reynolds IR. A review of direct orthodontic bonding. *Br J Orthod* 1975;2:171-8.

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