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Review Article

Evaluation of the effect of antimicrobial nanoparticles on bond strength of orthodontic adhesives: A review article

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ABSTRACT

Background: Antimicrobial nanoparticles (NPs) have various applications in different fields of dentistry. The purpose of incorporating NPs into orthodontic adhesives is to inhibit the cariogenic bacteria and reduce decalcifications around bonded orthodontic brackets. However, they may affect the physical and mechanical properties of adhesive such as shear bond strength (SBS). This review was done to answer the question whether the incorporation of antimicrobial NPs into orthodontic adhesives changes the SBS.

Materials and Methods: An electronic search was performed with keywords such as adhesives AND nanoparticles AND orthodontics AND shear strength. After screening and applying eligibility criteria, 18 relevant studies were included.

Results: The pooled data suggest that except for 10 wt% of various NPs incorporation, there is no significant difference in SBS between control conventional adhesives and experimental modified ones with tested concentrations.

Conclusion: The SBS of orthodontic adhesives containing up to 5% NPs is in clinical acceptable range. However, generalizing the results to *in vivo* situation may be problematic and further studies are required.

Key Words: Adhesives, nanoparticles, orthodontics, shear strength

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INTRODUCTION

Nanotechnology has been used for different medical purposes such as drug delivery and antimicrobial properties.[1-3] Nanomaterials are usually solid particles with a diameter of 1–100 nm, which are useful in antibacterial field because of their characteristics such as small sizes, large surface-to-volume ratio, and high chemical reactivity.[4] The high charge density of nanoparticles (NPs) causes interaction with the negatively charged surface of bacterial cells, which results in antimicrobial activity.[5] Application of nanomaterials in devices also causes improving the mechanical strength and efficiency of the systems.[6,7]

Organic and inorganic (metal) NPs such as gold (Au) and silver (Ag) and oxide particles such as zinc oxide (ZnO) and titanium dioxide (TiO_2)[8,9] have wide usage in various fields of dentistry such as endodontics, restorative dentistry, and orthodontics.[10,11] Bonding brackets with composite as an adhesive has been widely used in orthodontics. Unfortunately, despite many advantages,

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there are some problems with bonding technique such as debonding and demineralization around the brackets as a result of plaque formation.[12-14] An ideal bond strength prevents brackets from debonding during treatment, and it is not that high to cause tooth cracks during debonding.[15] Some factors including enamel conditioning techniques, adhesive systems, and design of the bracket base have been discussed to have effects on the bond strength.[16,17] Studies have reported that decalcification of dental surfaces occurs in about 50% to 75% of patients during fixed orthodontic treatment.[18,19] Maintenance of appropriate oral hygiene is problematic with fixed orthodontic appliances. They increase plaque formation and consequently white spot lesions around brackets, which increases the risk of caries.[20-22] In the oral cavity, combination of dental materials with NPs or coating surfaces with NPs are two mechanisms to reduce microbial adhesion.[23] Incorporating NPs to composite resins is found not only to have specific chemical and biological properties, such as the antibacterial effects, but also may affect their physical and mechanical features.[24] It is important not to change the shear bond strength (SBS) adversely, which will affect the clinical performance. Thus, this study aimed to review the published articles on the effects of adding antimicrobial NPs on bond strength of orthodontic adhesives.

MATERIALS AND METHODS

First, we defined a specific research question considering PICO format as shown in Table 1. To collect data, the following electronic databases were searched: EMBASE, SCOPUS, and MEDLINE from 2005 to March 2021. The keywords used in the search process were "orthodontics," "nanoparticles," "adhesives," and "shear strength." The collected articles were screened, assessed for eligibility, and included in the review process as shown in Figure 1. In details, the following inclusion criteria were applied for selection: (1) articles written in English, (2) *in vitro* studies, and (3) articles indicating SBS of orthodontic adhesives modified with antimicrobial NPs. The exclusion criteria were (1) articles discussing the primer or bonding agent of orthodontic adhesives, orthodontic cements, or other composite resins; (2) articles evaluating orthodontic adhesives containing other antimicrobial agents; and (3) studies experimenting nanofilled orthodontic adhesives. The duplicate records and review articles were also excluded. The authors reviewed the titles and abstracts. Then, the full texts of the selected ones were screened. The information of accepted ones was summarized and classified based on data collection forms with titles: first author, publication year, type of incorporated NPs, sample volume, tested concentrations of NPs, and clinical acceptable SBS.

Table 1: Population, intervention, control, and outcomes format

PICO items	Description
Population	Orthodontic adhesives
Intervention	Incorporation of antimicrobial nanoparticles
Comparison	Shear bond strength
Outcome	Affects the SBS beyond the acceptable range or not

SBS: Shear bond strength

RESULTS

According to the flow diagram in Figure 1, a total of 97 articles were identified through electronic database searching. Following duplicate removal, screening the title/abstracts, and applying eligibility criteria, 18 studies were included [Table 2]. 12 studies used human premolars, 5 used bovine incisors, and 1 study chose human molars to test the SBS of orthodontic adhesives.

For the evaluation of the effects of TiO_2 incorporation, four articles were collected. They reported that except for 10%, the other tested concentrations had no adverse effects on SBS. Four researches evaluated the effect of silver (Ag) NPs and reported that addition of small concentrations of Ag NPs (up to 1%) does not affect the SBS negatively. To evaluate each of copper (Cu),

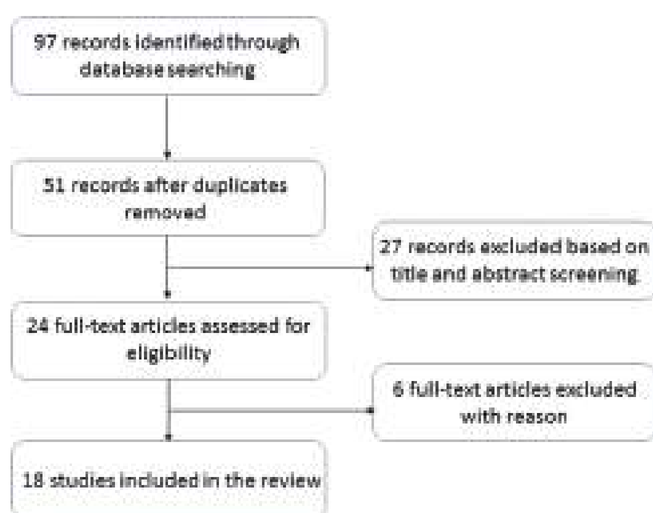

Figure 1: Flow diagram.

Table 2: Studies evaluating antimicrobial nanoparticles on shear bond strength of orthodontic adhesives

Author	Year	Type of Np*	Sample volume	Weight% of Np	Clinical acceptable SBS?
Ahmadi *et al.*[25]	2020	Cur-PLGA	50 human premolars in 5 groups of 10	0	Yes
				3	Yes
				5	Yes
				7	Yes
				10	No
Yaseen *et al.*[26]	2020	Cinnamon	20 human premolars in 2 groups of 10	0	Yes
				3	Yes
Eslamian *et al.*[27]	2020	Ag	34 human premolars in 2 groups of 17	0	Yes
				0.3	Yes
Assery *et al.*[28]	2019	TiO2	90 human premolars in 3 groups of 30	0	Yes
				1	Yes
				3	Yes
Sodagar *et al.*[29]	2019	Propolis	60 bovine incisors in 5 groups of 12	0	Yes
				1	Yes
				2	Yes
				5	Yes
				10	No
Pourhajibagher *et al.*[30]	2019	Cur-ZnO	60 human premolars in 6 groups of 10	0	Yes
				1.2	Yes
				2.5	Yes
				5	Yes
				7.5	Yes
				10	No
Behnaz *et al.*[31]	2018	TiO2	120 human premolars in 4 groups of 30 (with 2 composite brands)	0	Yes
				0.1	Yes
Toodehzaeim *et al.*[32]	2018	CuO	40 human premolars in 4 groups of 10	0	Yes
				0.01	Yes
				0.5	Yes
				1	Yes
Sodagar *et al.*[33]	2017	TiO2	48 bovine incisors in 4 groups of 12	0	Yes
				1	Yes
				5	Yes
				10	No
Felemban and Ebrahim[34]	2017	ZrO2-TiO2	30 human premolars in 3 groups of 10	0	Yes
				0.5	Yes
				1	Yes
Zaltsman and Kesler Shvero[35]	2017	QPEI	21 human molars in 3 groups of 7	0	Yes
				1	Yes
				1.5	Yes
Degrazia *et al.*[36]	2016	Ag	48 bovine incisors in 4 groups of 12	0	Yes
				0.11	Yes
				0.18	Yes
				0.33	Yes
Sodagar *et al.*[37]	2016	Cur	48 bovine incisors in 4 groups of 12	0	Yes
			Bovine incisors	1	Yes
			Bovine incisors	5	Yes
				10	No
Argueta Figueroa *et al.*[38]	2015	Cu	60 human premolars in 2 groups of 30	0	Yes
				0.01	Yes
Blöcher *et al.*[39]	2015	Ag	Bovine incisors in groups of 16	0	Yes
				0.11	Yes
				0.18	Yes
				0.33	Yes

Contd...

Table 2: Contd...

Author	Year	Type of Np*	Sample volume	Weight% of Np	Clinical acceptable SBS?
Akhavan *et al*.[40]	2013	Ag-HA	48 human premolars in 4 groups of 12	0	Yes
				1	Yes
				5	Yes
				10	No
Poosti *et al*.[41]	2012	TiO2	30 human premolars in 2 groups of 15	0	Yes
				1	Yes
Ahn *et al*.[42]	2009	Ag	Human premolars in groups of 17	0	Yes
				0.025	Yes
				0.05	Yes

Np: Nanoparticle; Cur: Curcumin; Cur-PLGA: Cur-poly lactic-co-glycolic acid; TiO2: Titanium dioxide; Cur-ZnO: Cur- zinc oxide; CuO: Copper oxide; ZrO2: Zirconium oxide; QPEI: Quaternary ammonium polyethyleneimine; Cu: Copper; Ag: Silver; Ag-HA: Silver hydroxyapatite; SBS: Shear bond strength

copper oxide (CuO), curcumin (Cur), cinnamon, quaternary ammonium polyethyleneimine (QPEI), propolis, zirconium oxide-TiO_2 (ZrO2-TiO2), curcumin-ZnO, curcumin-poly-lactic-co-glycolic acid, and silver-hydroxyapatite (Ag-HA) NPs, one study was found and their results reported that the SBS of adhesives containing these tested NPs up to 5% was in acceptable clinical range (5.9–7.8 MPa as suggested by Reynolds).[43]

DISCUSSION

The aim of antimicrobial NP incorporation in orthodontic adhesives is to reduce the microbial load in orthodontic patients, but they should not have adverse effects on adhesive SBS. This review article was performed to answer the question whether the combination of antimicrobial NPs with orthodontic adhesive compromises its SBS.

Based on the pooled data, incorporating up to 1 wt% Ag NPs maintained the SBS of orthodontic adhesives at acceptable level.[26,35,38,41] Yaseen *et al*.[25] evaluated addition of 3% nano-cinnamon and reported no adverse effects on SBS. Similarly, both tested concentrations of QPEI (1% and 1.5%)[34] revealed no significant difference in SBS compared to unmodified orthodontic adhesives as control group.

Addition of different percentages of ZrO2-TiO2 (0.5, 1 wt%),[33] Cu (0.01 wt%),[37] and CuO (0.01, 0.5, and 1 wt%)[31] was shown to have not only adverse effects on SBS but also increased it.

The results of the study by Sodagar *et al*.[29] on propolis NPs in 1%, 2%, 5%, and 10% wt/wt concentrations showed that incorporation of nano-propolis at the first three concentrations maintained the SBS within the acceptable clinical range. However, the 10% propolis NPs group had a significantly lower SBS, which was not recommended for clinical use. These results were in agreement with the results of the study done by Akhavan *et al*.[40] They stated that incorporation of 1% and 5% Ag-HA NPs maintained and increased the SBS of orthodontic adhesives, but the concentration of 10% had negative effect on it when compared to control group. Similar results were obtained in the study conducted by Flemban *et al*. on experimenting these three concentrations of ZrO2-TiO_2.[34] Similarly, in three other separate studies, Sodagar *et al*. compared the adhesives with 1%, 5%, and 10% Cur[37] and TiO_2[32] NPs and showed that mean shear bonds of composite containing 1% and 5% NPs were still in acceptable range. Based on Assery *et al*.'s[28] study results, adhesive with 1% TiO_2 offered the highest SBS followed by 3% TiO_2 Np and the control group of nonreinforced resin composite had the lowest SBS. However, both groups had acceptable clinical SBS. Behnaz *et al*.[31] also reported that the addition of TiO_2 NPs might decrease SBS, but the adhesion may still be in an acceptable range. Poosti *et al*.[41] showed equal SBS in the composite containing 1% TiO_2 NPs and the control group.

In all these studies, the SBS was evaluated in an *in vitro* environment. However, the forces may be different in oral cavity. There are various types of forces and tensions such as microbial plaque, temperature changes, and humidity *in vivo*, which causes the *in vitro* results to be interpreted carefully.[44] It is also recommended to assess the toxicity and biocompatibility of NPs with different concentrations in future studies.

CONCLUSION

Overall, the review of *in vitro* articles showed no significant difference among SBS of orthodontic adhesives with antimicrobial NPs and unmodified conventional orthodontic adhesives. To summarize, incorporation of all types of tested NPs up to 5 wt% offered clinically acceptable SBS.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

REFERENCES

1. Karimi-Maleh H, Fallah Shojaei A, Karimi F, Tabatabaeian K, Shakeri S. Au nanoparticle loaded with 6-thioguanine anticancer drug as a new strategy for drug delivery. J Nanostruct 2018;8:217-424.
2. Fathollahipour S, Ghaee A, Abouei Mehrizi A, Koosha M. Controlled antibiotic delivery by gelatin nanospheres: Optimization, characterization and antibacterial evaluation. J Nanostruct 2016;6:285-92.
3. Mohamadian F, Eftekhar L, Haghighi Bardineh Y. Applying GMDH artificial neural network to predict dynamic viscosity of an antimicrobial nanofluid. Nanomed J 2018;5:217-21.
4. Saafan A, Zaazou MH, Sallam MK, Mosallam O, El Danaf HA. Assessment of photodynamic therapy and nanoparticles effects on caries models. Open Access Maced J Med Sci 2018;6:1289-95.
5. Cao W, Zhang Y, Wang X, Li Q, Xiao Y, Li P, *et al*. Novel resin-based dental material with anti-biofilm activity and improved mechanical property by incorporating hydrophilic cationic copolymer functionalized nanodiamond. J Mater Sci Mater Med 2018;29:162.
6. Esmaeili J, Mohammadjafari A. Increasing flexural strength and toughness of cement mortar using multi-walled Carbon nanotubes. Int. J.Nano Dimens. 2014;5:399-407.
7. Parvaneh V, Shariati M, Nezakati A. Statistical analysis of the parameters influencing the mechanical properties of layered MWCNTs/PVC nanocomposites. Int. J Nano Dimens 2015;6:509-16.
8. Hernández-Sierra JF, Ruiz F, Pena DC, Martínez-Gutiérrez F, Martínez AE, Guillén AD, *et al*. The antimicrobial sensitivity of Streptococcus mutans to NPs of silver, zinc oxide, and gold. Nanomedicine 2008;4:237-40.
9. Poosti M, Ramazanzadeh B, Zebarjad M, Javadzadeh P, Naderinasab M, Shakeri MT. Shear bond strength and antibacterial effects of orthodontic composite containing TiO2 NPs. Eur J Orthod 2013;35:676-9.
10. Sharan J, Singh S, Lale SV, Mishra M, Koul V, Kharbanda P. Applications of nanomaterials in dental science: A review. J Nanosci Nanotechnol 2017;17:2235-255.
11. Ghorbani HR. The study of anticariogenic effect of Silver NPs for dental applications. Int J Nano Dimens 2017;8:361-4.
12. Mansour AY, Drummond JL, Evans CA, Bakhsh Z. *In vitro* evaluation of self-etch bonding in orthodontics using cyclic fatigue. Angle Orthod 2011;81:783-7.
13. Liu Y, Zhang L, Niu LN, Yu T, Xu HH, Weir MD, *et al*. Antibacterial and remineralizing orthodontic adhesive containing quaternary ammonium resin monomer and amorphous calcium phosphate NPs. J Dent 2018;72:53-63.
14. Restrepo M, Bussaneli DG, Jeremias F, Cordeiro RC, Magalhães AC, Palomari Spolidorio DM, *et al*. Control of white spot lesion adjacent to orthodontic bracket with use of fluoride varnish or chlorhexidine gel. ScientificWorldJournal 2015;2015:218452.
15. van Waveren Hogervorst WL, Feilzer AJ, Prahl-Andersen B. The air-abrasion technique versus the conventional acid-etching technique: A quantification of surface enamel loss and a comparison of shear bond strength. Am J Orthod Dentofacial Orthop 2000;117:20-6.
16. Dalaie K, Mirfasihi A, Eskandarion S, Kabiri S. Effect of bracket base design on shear bond strength to feldspathic porcelain. Eur J Dent 2016;10:351-5.
17. Rajesh RN, Girish KS, Sanjay N, Scindhia RD, Kumar SG, Rajesh S. Comparison of bond strength of brackets with foil mesh and laser structure base using light cure composite resin: An *in vitro* study. J Contemp Dent Pract 2015;16:963-70.
18. Ahn SJ, Lim BS, Lee SJ. Surface characteristics of orthodontic adhesives and effects on streptococcal adhesion. Am J Orthod Dentofacial Orthop 2010;137:489-95.
19. Cohen WJ, Wiltshire WA, Dawes C, Lavelle CL. Long-term *in vitro* fluoride release and rerelease from orthodontic bonding materials containing fluoride. Am J Orthod Dentofacial Orthop 2003;124:571-6.
20. Knösel M, Klang E, Helms HJ, Wiechmann D. Occurrence and severity of enamel decalcification adjacent to bracket bases and sub-bracket lesions during orthodontic treatment with two different lingual appliances. Eur J Orthod 2016;38:485-92.
21. Ogaard B, Rølla G, Arends J. Orthodontic appliances and enamel demineralization. Part 1. Lesion development. Am J Orthod Dentofacial Orthop 1988;94:68-73.
22. Ogaard B, Rølla G, Arends J, ten Cate JM. Orthodontic appliances and enamel demineralization. Part 2. Prevention and treatment of lesions. Am J Orthod Dentofacial Orthop 1988;94:123-8.
23. Allaker R. The use of NPs to control oral biofilm formation. J Dent Res 2010;89:1175-86.
24. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc 2003;134:1382-90.
25. Ahmadi H, Haddadi-Asl V, Ghafari HA, Ghorbanzadeh R, Mazlum Y, Bahador A. Shear bond strength, adhesive remnant index, and anti-biofilm effects of a photoexcited modified orthodontic adhesive containing curcumin doped poly lactic-co-glycolic acid nanoparticles: An *ex vivo* biofilm model of *S. mutans* on the enamel slab bonded brackets. Photodiagnosis Photodyn Ther 2020;30:101674.
26. Yaseen SN, Taqa AA, Al-Khatib AR. The effect of incorporation Nano Cinnamon powder on the shear bond of the orthodontic composite (an *in vitro* study). J Oral Biol Craniofac Res 2020;10:128-34.
27. Eslamian L, Borzabadi-Farahani A, Karimi S, Saadat S, Badiee MR. Evaluation of the shear bond strength and antibacterial activity of orthodontic adhesive containing silver nanoparticle, an *in vitro* study. Nanomaterials (Basel) 2020;10:1466.
28. Assery MK, Ajwa N, Alshamrani A, Alanazi BJ, Durgesh BH,

Matinlinna JP. Titanium dioxide NPs reinforced experimental resin composite for orthodontic bonding. Mater Res Express 2019;6:125098.
29. Sodagar A, Akhavan A, Arab S, Bahador A, Pourhajibagher M, Soudi A. Evaluation of the effect of propolis NPs on antimicrobial properties and shear bond strength of orthodontic composite bonded to bovine enamel. Front Dent 2019;16:96.
30. Pourhajibagher M, Salehi Vaziri A, Takzaree N, Ghorbanzadeh R. Physico-mechanical and antimicrobial properties of an orthodontic adhesive containing cationic curcumin doped zinc oxide nanoparticles subjected to photodynamic therapy. Photodiagnosis Photodyn Ther 2019;25:239-46.
31. 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. Dental Press J Orthod 2018;23:43.e1- 43.e7.
32. Toodehzaeim MH, Zandi H, Meshkani H, Firouzabadi AH. The effect of CuO NPs on antimicrobial effects and shear bond strength of orthodontic adhesives. J Dent 2018;19:1.
33. Sodagar A, Akhoundi MSA, 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.
34. Felemban NH, Ebrahim MI. The influence of adding modified zirconium oxide-titanium dioxide nano-particles on mechanical properties of orthodontic adhesive: An *in vitro* study. BMC Oral Health 2017;17:43.
35. Zaltsman N, Kesler Shvero D. Antibacterial orthodontic adhesive incorporating polyethyleneimine NPs. Oral Health Prev Dent 2017;15:245-50.
36. Degrazia FW, Leitune VC, Garcia IM, Arthur RA, Samuel SM, Collares FM. Effect of silver NPs on the physicochemical and antimicrobial properties of an orthodontic adhesive. J Appl Oral Sci 2016;24:404-10.
37. Sodagar A, Bahador A, Pourhajibagher M, Ahmadi B, Baghaeian P. Effect of addition of curcumin NPs on antimicrobial property and shear bond strength of orthodontic composite to bovine enamel. J Dent (Tehran, Iran) 2016;13:373.
38. Argueta-Figueroa L, Scougall-Vilchis RJ, Morales-Luckie RA, Olea-Mejía OF. An evaluation of the antibacterial properties and shear bond strength of copper nanoparticles as a nanofiller in orthodontic adhesive. Aust Orthod J 2015;31:42-8.
39. Blöcher S, Frankenberger R, Hellak A, Schauseil M, Roggendorf MJ, Korbmacher-Steiner HM. Effect on enamel shear bond strength of adding microsilver and nanosilver particles to the primer of an orthodontic adhesive. BMC Oral Health 2015;15:42.
40. 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.
41. 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 Orthod 2013;35:676-9.
42. Ahn SJ, Lee SJ, Kook JK, Lim BS. Experimental antimicrobial orthodontic adhesives using nanofillers and silver NPs. Dent Mater 2009;25:206-13.
43. Reynolds IR. A review of direct orthodontic bonding. Br J Orthod 1975;2:171-8.
44. Fernandez L, Canut JA. *In vitro* comparison of the retention capacity of new aesthetic brackets. Eur J Orthod 1999;21:71-7.