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

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,
there are some problems with bonding technique such as debonding and demineralization around the brackets as a result of plaque formation. An ideal bond strength prevents brackets from debonding during treatment, and it is not that high to cause tooth cracks during debonding. Some factors including enamel conditioning techniques, adhesive systems, and design of the bracket base have been discussed to have effects on the bond strength. Studies have reported that decalcification of dental surfaces occurs in about 50% to 75% of patients during fixed orthodontic treatment. 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. In the oral cavity, combination of dental materials with NPs or coating surfaces with NPs are two mechanisms to reduce microbial adhesion. 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. 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.

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 TiO₂ 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),

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

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                     |
| Zaitsman 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                     |
|                      |      |             |                                                       | 1             | Yes                     |
|                      |      |             |                                                       | 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...
copper oxide (CuO), curcumin (Cur), cinnamon, quaternary ammonium polyethyleneimine (QPEI), propolis, zirconium oxide-TiO$_2$ (ZrO$_2$-TiO$_2$), 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).

**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.\cite{26,35,38,41} Yaseen et al.\cite{25} evaluated addition of 3% nano-cinnamon and reported no adverse effects on SBS. Similarly, both tested concentrations of QPEI (1% and 1.5%)\cite{34} revealed no significant difference in SBS compared to unmodified orthodontic adhesives as control group.

Addition of different percentages of ZrO$_2$-TiO$_2$ (0.5, 1 wt%),\cite{33} Cu (0.01 wt%),\cite{37} and CuO (0.01, 0.5, and 1 wt%)\cite{31} was shown to have not only adverse effects on SBS but also increased it.

The results of the study by Sodagar et al.\cite{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.\cite{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 ZrO$_2$-TiO$_2$.\cite{34} Similarly, in three other separate studies, Sodagar et al. compared the adhesives with 1%, 5%, and 10% Cur and TiO$_2$ 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\cite{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.\cite{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.\cite{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.\cite{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
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