Original Article

Effect of silver and zinc oxide nanoparticles on the tensile strength of a denture tissue conditioner

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Abstract

Objective: Low tensile strength is one of the problems of tissue conditioning materials used in complete prostheses. This study aimed to explore the impact of silver (Ag) and zinc oxide (ZnO) nanoparticles (NPs) on the tensile strength of a tissue conditioner.

Methods: Ag and ZnO NPs were synthesized using the light bulb method and verified by scanning electron microscopy, X-ray powder diffraction, and Fourier transform infrared spectroscopy (FTIR). The prepared NPs were mixed with the tissue-conditioner fluid at weight percentages (wt%) of 0.675, 1.25, 2.5, 5, and 10. The NPs were added either individually (Ag or Zn alone) or in combination (at a ratio of ½ Ag and 1/2 ZnO). Tensile strength was measured on rectangular cube specimens with dimensions of 2 x 20 x 200 mm using a universal testing machine according to the ISO 17025 standard. The results were analyzed by one-way analysis of variance (ANOVA) and Tukey test at a significance level of $P<0.05$.

Results: The concentration of 5% and 10% Ag NPs increased the tensile strength of the tissue conditioner ($P<0.05$), but the addition of ZnO NPs at any concentration (up to wt. of 10%) did not ($P>0.05$). The combined application of Ag and ZnO NPs at concentrations of 5% and 10% was also effective in enhancing the tensile strength ($P<0.05$).

Conclusions: The addition of Ag or Ag-ZnO NPs at concentrations of 5% and 10% may be suggested to enhance the tensile strength of the tissue conditioning materials. *(J Dent Mater Tech 2023;12(2):55-60)*

Keywords: *Nanoparticles, Silver, Tensile strength, Tissue conditioner, Zinc oxide*

Introduction

Tissue conditioners are flexible materials applied on the fitting surface of a denture for providing better force distribution and thus treatment of tissue inflammation and enhancement of tissue healing (1, 2). These materials maintain their elastic quality for a short time, during which they cause an even distribution of forces (3, 4). Ideally, the conditioner should be replaced every 3-4 days (5). In these materials, the loss of plasticizers leads to the hardening of the material, affecting surface integrity and viscoelasticity (6, 7). Another problem with using tissue-conditioning materials is their low tensile strength. It has been demonstrated that it is possible to increase the chemical bond strength between the polymers used in soft liners.

One of the methods that have attracted the attention of researchers in the last decade is the addition of metal nanoparticles (NPs), to improve the mechanical properties of dental materials (8). Nanoparticles, as novel dental materials, are widely used in different branches of dentistry to improve the quality of products. The addition of NPs into restorative and prosthetic materials is an approved strategy to enhance their mechanical properties and compressive strength (9, 10).

Zinc oxide (ZnO) NPs have been widely investigated over the past two decades due to their superior antibacterial, antifungal, electrical, chemical, and optical properties. Zinc oxide nanoparticles can be synthesized using numerous techniques. ZnO demonstrated superior biocompatibility over many other metal oxides and has

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found many notable applications in antiviral, antimicrobial, biomedical, and environmental fields (10). The addition of ZnO nanocrystals to dental materials has recently attracted the attention of researchers (11). Zinc oxide is recognized as a safe substance by the US Department of Food and Drug Administration (12).

Silver nanoparticles (Ag NPs) possess good tissue compatibility and exhibit minimal toxic effects (8). The effect of Ag NPs on the physical characteristics of the denture depends on various factors, such as the weight percentage (wt. %) of NPs and the type of acryl. Studies have shown that the wt. % of 1, 5, 10, 20, and 30 of Ag NPs improve mechanical properties, compressive strength, and antifungal effects (14,15,16), however, the tensile strength was negatively impacted after the incorporation of nanosilver (15).

Previous studies have examined the effects of Ag and ZnO NPs separately on the strength of tissue conditioners. However, the number of these studies is limited, and the effect of their concurrent addition on tissue conditioner properties has not been investigated to the best of our knowledge. This study aimed to investigate whether the addition of different concentrations of Ag and ZnO NPs (individually or in combination) to a tissue conditioning material can affect its tensile strength.

Materials and Methods

The study protocol was approved by the Ethics Committee of Tabriz University of Medical Sciences, Tabriz, Iran (Ethical code: IR.Tbzmed.REC.1396.295).

Nanoparticle synthesis

In the present study, the method proposed by Mousavi et al. (17) was used for the synthesis of NPs.

Evaluation of the dimensions and morphology of nanoparticles

The morphological properties of the particles were evaluated by scanning electron microscopy (SEM; Hitachi su3500, Japan). The NPs were dissolved in distilled water and then coated with a thin layer of gold. The dimensions of Ag and ZnO NPs were measured by images taken at 40K magnification.

Elemental analysis

The crystalline phases in the synthesized magnetic NPs were studied using X-ray diffraction analysis. The scaffolds were scanned in the range of 20-100˚. In NP-related crystals, the strongest peak was used to determine the average size of the crystals.

Fourier-transform infrared spectroscopy (Thermo Scientific, Waltham, MA, USA) was employed to observe the chemical composition of the NP samples.

Adding nanoparticles to the tissue conditioner

The synthesized NPs (Ag, ZnO, and Ag-ZnO) were uniformly mixed with the tissue conditioning fluid (GC Tissue Conditioner; GC America Inc., Il, USA) at wt. % of 0.675, 1.25, 2.5, 5, or 10. The NPs were added either individually (Ag or Zn alone) or in combination (at a ratio of ½ Ag and 1/2 ZnO).

Tensile strength evaluation

To evaluate the tensile strength, specimens were made in the form of rectangular cubes with dimensions of 2 x 20 x 200 mm according to the ISO 1567 standard (Figure 1).

To measure the tensile strength under the ISO 17025 standard, the specimens were tested using a universal machine (Zwick Z/100, Frankfurt, Germany). The device applied tensile force to the sample at a speed of 5 mm per min from the free end, and the force at breaking was determined by the device.

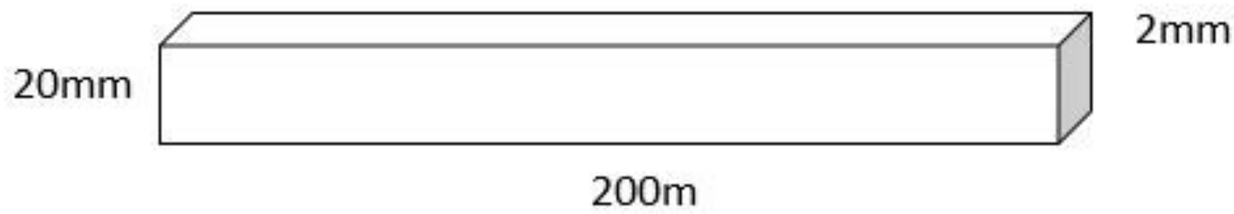

Figure 1. A standard sample of the tensile strength testing

Statistical analysis

The power & sample size calculation software (version 3.0) was used to determine the sample size (α=0.05 and power=80%) (18, 19). Four samples were calculated for each of the study groups, which was increased to 5 samples per group (16 groups: three substances and five concentrations, as well as a control group) to increase reliability.

One-way analysis of variance (ANOVA) and Tukey post hoc test were used to compare tensile strength at weight percentages of 0.675, 1.25, 2.5, 5, and 10 of NPs.

Results

Elemental analysis and morphology evaluation

Figure 2 shows the scanning electron microscopy images of the prepared NPs. After a careful evaluation of different areas of the sample, the size of magnetic NPs was determined to be between 40 and 1000 nm.

The X-ray diffraction analysis (Figure 3) revealed that the samples were in complete agreement with the reference's spectral lines.

The successful synthesis of Ag and ZnO NPs was confirmed by assessing the absorption bands related to the reactive groups of each NP in the infrared (IR) spectrum (Figure 4).

Mechanical test

The addition of Ag or Ag-ZnO NPs up to wt.% of 2.5% and the addition of ZnO NPs at any wt. % did not change the tensile strength of the tissue conditioner (P>0.05). However, the specimens incorporated with 5% and 10% wt.% of Ag or Ag-ZnO NPs showed a significant improvement in tensile strength as compared to the control group (P<0.05; Table 1).

Discussion

Studies have shown that metal NPs in high-weight percentages affect the polymerization process of dental materials and reduce their biocompatibility, necessitating the use of minimum effective concentrations (15, 20). In the present study, incorporating Ag NPs by wt. % of up to 2.5% to the tissue conditioner did not change its tensile strength. Increasing the wt. % of Ag NPs to 5% and 10% resulted in a significant increase in tensile strength. It appears that a minimum threshold concentration of NPs is required to achieve the desired improvement in material properties.

The outcomes of this study are in agreement with the results of Rostamkhani et al. (16) who showed that the mechanical properties of samples containing a low percentage of nanosilver (2%) did not change significantly, however, increasing the wt.% of nanosilver by 4% and 6% caused a significant increase in mechanical properties of conventional tissue conditioners. Mahross and Baroudi (21) demonstrated that the viscoelastic properties of acrylic resin added with 5% Ag NPs were significantly better than other concentrations. Nam et al. (14) indicated that the addition of Ag NPs to acrylic resin improved its mechanical properties. In contrast, Ueshige et al. (22) showed that the incorporation of antimicrobial silver-zeolite changed viscoelastic properties in several brands of tissue conditioners. Hamedi-Rad et al. (15) reported that the concentration of 5% nanosilver negatively affected the tensile strength of acrylic resin. Habibzadeh et al. (23) found that the addition of 0.5, 1, 2, and 3 wt% of Ag NPs to Mucopren soft linear reduced its tensile bond strength to the prosthetic acrylic resin. Mollazadeh et al. (24) stated that tensile strength and stiffness were less sensitive to added materials.

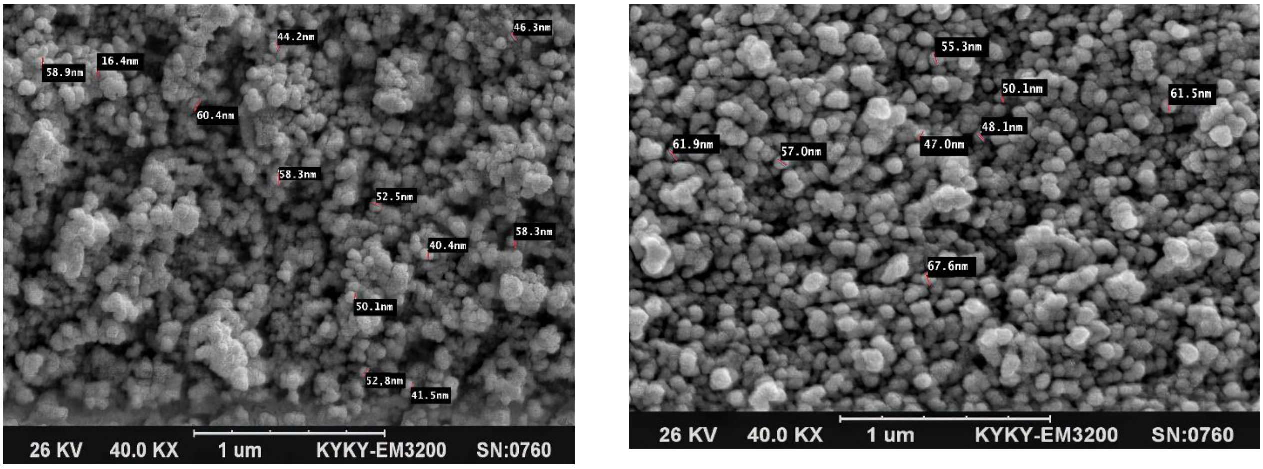

Figure 2. Scanning electron microscopy images of silver nanoparticles (left) and zinc oxide nanoparticles (right)

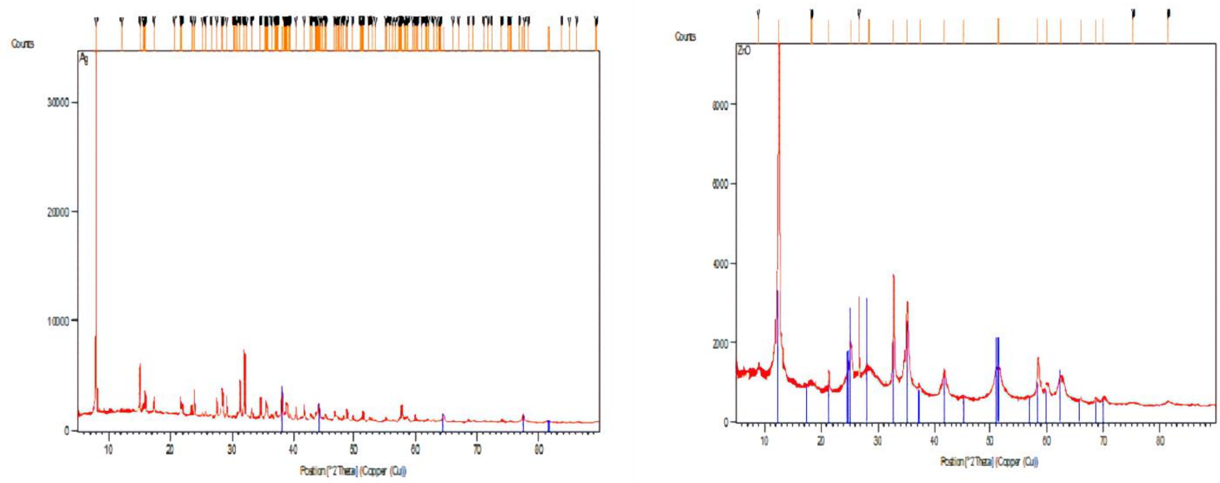

Figure 3. X-ray diffraction images of silver nanoparticles (left) and zinc oxide nanoparticles (right)

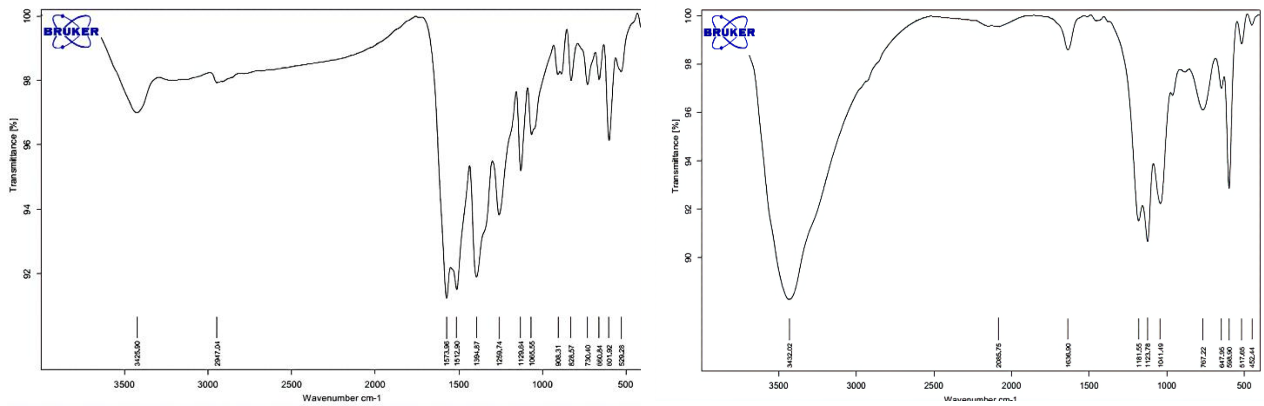

Figure 4. Fourier-transform infrared analysis images of silver nanoparticles (left) and zinc oxide nanoparticles (right)

Table 1. Comparison of tensile strength of tissue conditioning materials containing different percentages of silver (Ag), zinc oxide (Zn), and silver-zinc oxide (Ag-ZnO) nanoparticles

Concentration	Silver	Zinc oxide	Silver-zinc oxide
	Mean ± SD	Mean ± SD	Mean ± SD
0.675%	10.68 ± 3.208	10.23 ± 2.305	11.23 ± 3.41
1.25%	10.72 ± 2.273	10.57 ± 2.98	11.76 ± 2.95
2.50%	11.23 ± 4.151	10.88 ± 3.35	12.3 ± 2.82
5%	12.4 ± 3.340*	11.2 ± 3.04	13.4 ± 3.56*
10%	15.3 ± 4.62*	11.5 ± 2.62	15.9 ± 4.2*
Control	10.41 ± 2.23	10.41 ± 2.23	10.41 ± 2.23
p-value	<0.001	<0.001	<0.001

SD, standard deviation; *indicates a statistically significant difference to the control group at P<0.05.

The addition of ZnO NPs at any wt.% (up to 10%) was not effective in improving the tensile strength of the tissue conditioner in the present investigation. Some authors suggested that the ineffectiveness of ZnO NPs may be due to the lack of a strong chemical bond between the NPs and the polymers, or the improper dispersion of ZnO NPs, which led to an even rougher tissue morphology (25). Khan et al. (26) also found no significant difference in the flexural strength of acrylic resin reinforced by ZnO NPs.

In the present study, the combination of Ag and ZnO NPs up to wt.% of 2.5 was not effective in enhancing the tensile strength of the tissue conditioner. However, increasing the wt. % of Ag-ZnO NPs to 5% and 10% significantly improved the tensile strength of the tissue conditioner. The amount of increase in tensile strength at these two concentrations was slightly greater than that of the Ag NPs alone. The combined application of Ag and ZnO NPs may lead to the formation of modified ZnO NPs, which strengthen the bond between the NPs and the tissue conditioning material. It may also create a more homogeneous morphology, thus increasing the mechanical properties of the tissue conditioner. To the best of the authors' knowledge, no study has yet investigated the effect of the simultaneous addition of Ag and ZnO NPs to tissue conditioners.

The reason for the difference in research results among the studies can be due to various factors, such as the preparation method and type of material, as well as the amount and size of added NPs. Additionally, it should be noted that structural defects, such as bubbles, during construction can impact the test results. The authors recommend investigating other mechanical properties, including roughness, stiffness, flexural strength, and heat transfer of tissue conditioning materials after the addition of silver and ZnO NPs.

Conclusions

Under the conditions used in this study:

1- The incorporation of Ag NPs and the combination of Ag and ZnO NPs at wt.% of 5% and 10% improved the tensile strength of tissue conditioning material. Therefore, incorporating these NPs is suggested to enhance the mechanical properties of tissue conditioners.

2- The addition of ZnO NPs alone at any concentration (up to the wt.% of 10%) did not enhance the tensile strength of the tissue conditioning material.

References

1. Rathore P, Hegde A, Ginjupalli K, Upadhya N. Evaluation of antifungal activity of additives to resilient liners: an in vitro pilot study. Trends Biomater Artif Organs 2009;23(1):6-9.

2. Muniz IA, Campos DE, Ribeiro I, Rodrigues WF, da Silva SD, Batista AU, et al. Antimicrobial Activity in Chitosan-Treated Prosthetic Materials: A Systematic Review. Eur J Prosthodont Restor Dent 2022.

3. Ebadian B, Navarchian AH, Sedighipour L. The Effect of Surface Coating on Softness of Two Kinds of Tissue Conditioners. Dent Res J 2008;3(1):14-18.

4. Malmström HS, Mehta N, Sanchez R, Moss ME. The effect of two different coatings on the surface integrity and softness of a tissue conditioner. J Prosthet Dent 2002;87(2):153-157.

5. Arutyunov AS, Shanidze ZL, Tsareva EV, Arutyunov SD. Prosthodontic treatment of edentulous patients with postoperative mandibular defects of oncological origin. Stomatologiia 2018;97(1):54-58.

6. Nam K-Y. In vitro antimicrobial effect of the tissue conditioner containing silver nanoparticles. J Adv Prosthodont 2011;3:20-24.

7. Bates J, Smith D. Evaluation of indirect resilient liners for dentures: laboratory and clinical tests. J Am Dent Assoc. 1965;70(2):344-353.

8. Kalbassi MR, Abdollahzade E, Salari Joo H. Effect of colloidal silver nanoparticles on population of gut bacterial flora of rainbow trout (Oncorhynchus mykiss). J Vet Res 2012;67(2):181-189.

9. Pai E, Nayak A, Hallikerimath RB, Ruttonji Z, Astagi P, Pokale S. Comparison of titanium dioxide nanoparticles and silver nanoparticles for flexural strength once incorporated in heat-cure acrylic denture base resin: An in vitro Study. J Indian Prosthodont Soc 2023;23(2):127-134.

10. Pushpalatha C, Suresh J, Gayathri VS, Sowmya SV, Augustine D, Alamoudi A, et al. Zinc Oxide Nanoparticles: A Review on Its Applications in Dentistry. Front Bioeng Biotechnol 2022; 19(10):818.

11. Sousa C, Pereira M, Almeida R, Loyola A, Silva A, Dantas N. Synthesis and characterization of zinc oxide nanocrystals and histologic evaluation of their

biocompatibility by means of intraosseous implants. Int Endod J 2014;47(5):416-424.

12. Rajendra R, Balakumar C, Ahammed HAM, Jayakumar S, Vaideki K, Rajesh E. Use of zinc oxide nano particles for production of antimicrobial textiles. Int J Eng Sci Tech 2010;2(1):202-208.

13. Habibzadeh S, Eskandarion S, Marashi SMA, Yunesi G, Kharazifard M. Antifungal Efficacy of a Permanent Silicon Soft Liner Containing Silver Nanoparticles. Front Dent 2021;18:8.

14. Nam KY, Lee CH, Lee CJ. Antifungal and physical characteristics of modified denture base acrylic incorporated with silver nanoparticles. Gerodontology 2012;29(2):e413-e419.

15. Hamedi-Rad F, Ghaffari T, Rezaii F, Ramazani A. Effect of nanosilver on thermal and mechanical properties of acrylic base complete dentures. J Dent (Tehran) 2014;11(5):495-505.

16. Rostamkhani F, Gharechahi J, Zebarjad S, Bahrami M, Esmaeili H. Comparative Evaluation of Elastic Strain, Permanent Strain and Shore A Hardness in Conventional Tissue Conditioners. J Masht Dent Sch 2010;34(4):291-298.

17. Mousavi SA, Ghotaslou R, Akbarzadeh A, Azima N, Aeinfar A, Khorramdel A. Evaluation of antibacterial and antifungal properties of a tissue conditioner used in complete dentures after incorporation of ZnO–Ag nanoparticles. J Dent Res Dent Clin Dent Prospects 2019;13(1):11-18.

18. Hojati ST, Alaghemand H, Hamze F, Babaki FA, Rajab-Nia R, Rezvani MB, et al. Antibacterial, physical and mechanical properties of flowable resin composites containing zinc oxide nanoparticles. Dent Mater 2013;29(5):495-505.

19. Zhang L, Ding Y, Povey M, York D. ZnO nanofluids–A potential antibacterial agent. Prog Nat Sci 2008;18(8):939-944.

20. Chladek G, Kasperski J, Barszczewska-Rybarek I, Żmudzki J. Sorption, solubility, bond strength and hardness of denture soft lining incorporated with silver nanoparticles. Int J Mol Sci 2013;14(1):563-574.

21. Mahross HZ, Baroudi K. Effect of silver nanoparticles incorporation on viscoelastic properties of acrylic resin denture base material. Eur J Dent 2015;9(02):207-212.

22. Ueshige M, Abe Y, Sato Y, Tsuga K, Akagawa Y, Ishii M. Dynamic viscoelastic properties of antimicrobial tissue conditioners containing silver-zeolite. J Dent 1999;27(7):517-522.

23. Habibzadeh S, Omidvaran A, Eskandarion S, Shamshiri AR. Effect of incorporation of silver nanoparticles on the tensile bond strength of a long term soft denture liner. Eur J Dent 2020;14(02):268-273.

24. Mollazadeh S, Javadpour J, Eftekhari Yekta B, Jafarzadeh T, Youssefi A. Synthesis and characterisation of dental composite materials reinforced with fluoroapatite–mullite glass–ceramic particles. Adv Appl Ceram 2013;112(5):294-300.

25. Li X, Li W, Jiang Y, Ding Y, Yun J, Tang Y, et al. Effect of nano-ZnO-coated active packaging on quality of fresh-cut 'Fuji'apple. Int J Food Sci Technol 2011;46(9):1947-1955.

26. Khan H, Raza M, Khan TA. Comparison of flexural strength of zinc nanoparticles reinforced resin with conventional heat cured acrylic resin. Pak Oral Dent J 2020;40(1):51-54.