

DOI: doi:10.58240/1829006X-2025.21.10-146



## ORIGINAL RESEARCH

## NANOSTRUCTURED ZINC OXIDE-COATED GUTTA-PERCHA FOR ENHANCED ROOT CANAL OBTURATION

Manobharathi G<sup>1</sup> Sandhya Raghu<sup>2\*</sup>

<sup>1</sup> Post graduate student, Department of Conservative Dentistry and Endodontics, Saveetha Dental college and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-600077

<sup>2</sup> Professor, Department of Conservative Dentistry and Endodontics, Saveetha Dental college and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-600077

\*Corresponding author: Sandhya Raghu, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-600077, [sandhya.sdc@saveetha.com](mailto:sandhya.sdc@saveetha.com)

*Received: Sep. 21, 2025; Accepted: Oct 25, 2025; Published: Oct 30, 2025*

## Abstract

**Background:** Gutta-percha (GP) cones are widely used for root canal obturation, but conventional disinfection methods and limited antibacterial activity can compromise their efficacy, potentially leading to endodontic treatment failure. Nanostructured coatings offer a promising approach to enhance the physicochemical and antimicrobial properties of GP cones.

**Aim:** To develop and characterize zinc oxide (ZnO) nanoparticle-coated GP cones to improve surface properties and potential antibacterial activity for enhanced root canal obturation.

**Materials and Methods:** ZnO nanoparticles were synthesized via chemical precipitation, characterized for size and morphology, and incorporated into a polyvinyl alcohol (PVA) matrix to prepare a uniform coating suspension. Sterilized GP cones (size 80) were divided into two groups: uncoated (control) and ZnO–PVA-coated (experimental). Coating was achieved via a dip-coating technique with multiple drying cycles. Surface morphology, elemental composition, chemical functional groups, and crystallinity of the coated cones were evaluated using scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD).

**Results:** SEM revealed a uniform nanostructured coating on GP cones, increasing surface roughness and surface area. EDS confirmed the presence of Zn and O in stoichiometric proportions, while FTIR showed characteristic Zn–O and OH vibrations, indicating chemical stability. XRD analysis confirmed the high crystallinity and phase purity of ZnO nanoparticles. The coating exhibited strong adhesion without cracks or delamination, suggesting enhanced physicochemical stability.

**Conclusion:** ZnO–PVA-coated GP cones demonstrate improved surface characteristics, including increased roughness, surface area, and reactivity, which may enhance adhesion to root canal sealers and provide potential antibacterial benefits. This nanostructured coating represents a promising strategy for functionalizing GP cones to reduce microbial colonization and improve the success of endodontic treatment. Further studies are warranted to assess direct antimicrobial efficacy, sealer interaction, and long-term clinical performance.

**Keywords:** Gutta-percha, Zinc oxide nanoparticles, Root canal obturation, Nanostructured coating, Endodontic materials

## INTRODUCTION

Endodontic therapy is performed to manage infected dental pulp, with the primary objectives of eliminating infection and preventing reinfection<sup>1</sup>. Following pulp removal, the root canal space is thoroughly cleaned, shaped, and filled with a core root filling material<sup>1,2</sup>. Effective irrigation and precise biomechanical preparation are crucial to the success of endodontic treatment<sup>3-5</sup>. The purpose of root filling is to preserve the aseptic chain established during earlier treatment stages<sup>1</sup>. Gutta-percha (GP) cones are the most widely used root canal filling material because of their biocompatibility, cost-effectiveness, long-standing clinical use, and potential antibacterial properties, largely attributed to their zinc oxide (ZnO) component<sup>6</sup>. ZnO exhibits strong antibacterial activity through interactions with bacterial surfaces and/or cellular components<sup>7</sup>. Despite this, endodontic treatment may fail due to persistent or secondary root canal infection<sup>8</sup>. *Enterococcus faecalis*, in particular, is a highly resilient intra-canal pathogen frequently associated with treatment failures<sup>8</sup>.

Furthermore, although GP cones are produced under aseptic conditions, several studies have reported microbial contamination in newly opened packages, which increases with improper storage, aerosol exposure, and handling<sup>1</sup>. *Staphylococcus* spp. is one of the most common contaminants found in GP cones after inadequate handling. Immersing GP cones in disinfectants is a conventional decontamination method that both cleanses the material and imparts antibacterial activity<sup>6</sup>. Sodium hypochlorite (NaOCl) is commonly used for this purpose due to its low cost and broad-spectrum antimicrobial effect. However, NaOCl may adversely affect the physical properties of GP cones, including elasticity, tensile strength, and elongation, which could compromise the quality of root canal filling<sup>9,10</sup>. Consequently, alternative physicochemical approaches have been explored to enhance the antibacterial efficacy of GP cones while maintaining their functional properties. These include incorporating antimicrobial agents such as chlorhexidine, calcium hydroxide, or bioactive phosphate glasses, as well as advanced nanotechnology-based strategies such as nanodiamond–GP composites<sup>6</sup>.

GP cones are composed of approximately 20% gutta-percha (matrix), 66% zinc oxide (filler), 11% heavy metal sulfates (radiopacifier), and 3% waxes and/or resins (plasticizer)[6]. Modifications of gutta-percha (GP) are intended to enhance the effectiveness, safety, and durability of root canal treatments, ultimately improving patient outcomes. To achieve this, various physicochemical strategies have been explored to increase the antibacterial activity of GP cones

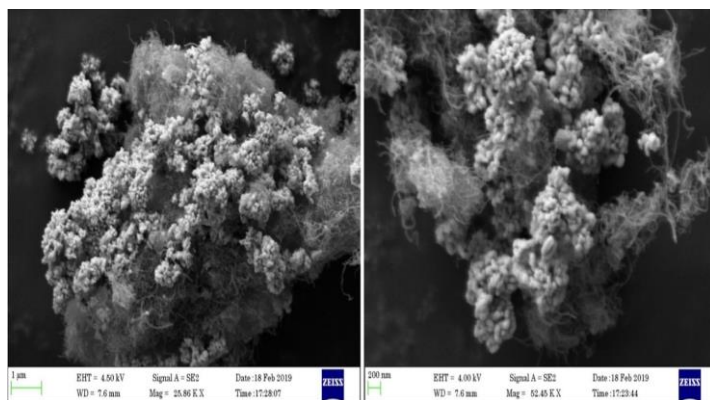
while preserving their obturation properties. These approaches include the incorporation of antimicrobial agents such as chlorhexidine, calcium hydroxide, and bioactive phosphate glasses, as well as nanoscale techniques like the development of nanodiamond–GP composites<sup>11</sup>. This modification is essential for reducing the bacterial load within the root canal, minimizing the risk of reinfection, and ultimately improving clinical outcomes. By integrating antibacterial materials into GP, the likelihood of posttreatment infections can be reduced. The aim of this study is to enhance physicochemical characteristics, functionalization, and surface activation of GP cones through zinc oxide nanoparticle coating.

## MATERIALS AND METHODS

### Synthesis of Zinc Oxide Nanoparticles

Zinc oxide nanoparticles (ZnO-NPs) were synthesized using a chemical precipitation method. Zinc acetate dihydrate ( $\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$ ) served as the precursor, and sodium hydroxide (NaOH) was used as the precipitating agent. Briefly, equimolar solutions of zinc acetate and sodium hydroxide were prepared in distilled water and adjusted to pH values of 8 and 11, respectively. The two solutions were mixed under constant stirring at room temperature for 30 minutes to facilitate nucleation and growth of nanoparticles. The resulting precipitate was filtered, thoroughly washed with distilled water to remove impurities, and dried in a hot air oven at 80 °C for 5 hours.

Subsequently, the dried powder was subjected to calcination at 400 °C for 1 hour in a muffle furnace to improve crystallinity and remove residual organic matter. The final product consisted of pure ZnO nanoparticles. Surface morphology and particle size of the synthesized nanoparticles were characterized using scanning electron microscopy (SEM) (Fig 1).



**Figure 1.** SEM images of the pure Zinc oxide nanoparticle

### Preparation of ZnO–PVA Coating Medium

Polyvinyl alcohol (PVA) was used as a polymeric binder and dispersing agent to facilitate uniform nanoparticle coating on gutta-percha (GP) cones. A 5% (w/v) PVA solution was prepared by dissolving PVA granules in distilled water at 80 °C under continuous stirring until a clear solution was obtained. The synthesized ZnO nanoparticles were then gradually added to the PVA solution at a concentration of 1% (w/v) and dispersed using ultrasonication for 30 minutes to achieve a homogeneous nanoparticle–polymer suspension.

### Sterilization of Gutta-Percha Cones

Commercially available GP cones (size 80; Dentsply Maillefer, Switzerland) were used in this study. To eliminate any pre-existing microbial contamination, the cones were sterilized using ethylene oxide gas sterilization and stored in sterile containers prior to coating.

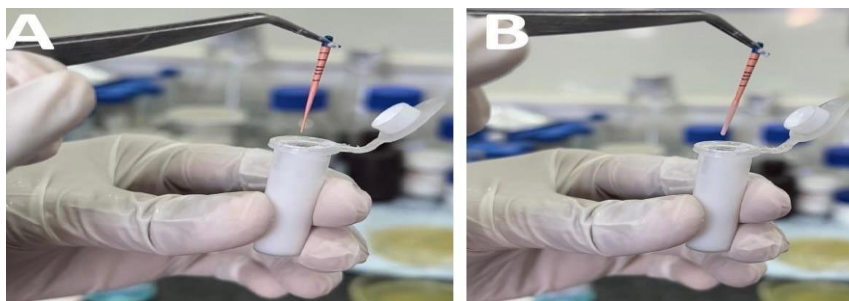
### Coating of Gutta-Percha Cones

The sterilized cones were divided into two groups:

- Group A – Uncoated GP (control)
- Group B – ZnO-coated GP (experimental)

For surface modification, cones in Group B were coated with ZnO nanoparticles using a dip-coating technique. The cones were immersed in the ZnO–PVA suspension for 5 minutes to ensure uniform adhesion of the nanoparticle film. After withdrawal, the cones were air-dried under laminar airflow conditions to allow solvent evaporation. To achieve a stable and uniform thin-film coating, the dipping and drying process was repeated three times.

The dip-coating technique was chosen as it allows three-dimensional surface coverage and ensures deposition of a continuous ZnO nanoparticle film around the GP cones ( Fig 2 ). The coated cones were further dried at 50 °C for 2 hours in a hot air oven to enhance polymer crosslinking and adhesion of nanoparticles to the GP surface.



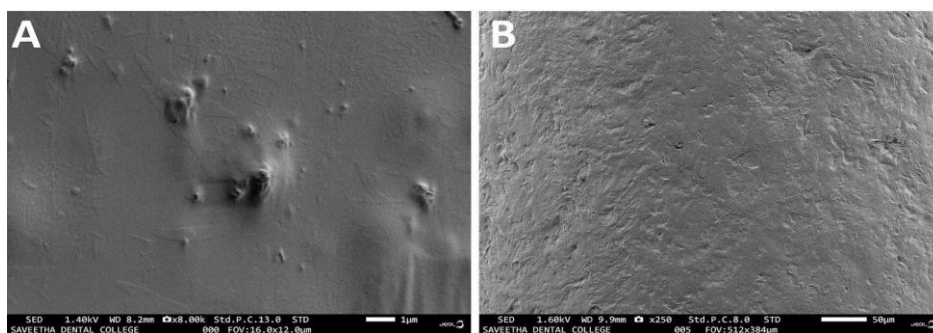
**Figure 2.** Sterilised Gutta Percha before coating(A),Coating Gutta Percha with polymer incorporated with Zinc oxide ( B).

## RESULTS

### Scanning Electron Microscopy (SEM)

The surface morphology of uncoated and ZnO-coated GP cones was examined using SEM (Fig. 3a, b). Uncoated GP cones exhibited a relatively smooth and featureless surface with minimal irregularities, characteristic of the pristine polymer matrix. In contrast, ZnO-coated cones displayed a distinct nanostructured surface. The ZnO–PVA coating appeared as a continuous thin film covering the cone surface, with fine granular features distributed homogeneously. The nanoparticles

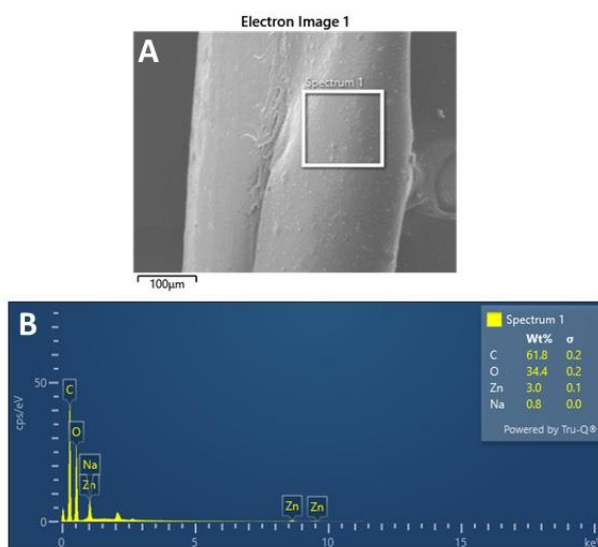
were embedded within the PVA matrix, producing a roughened texture compared with the uncoated cones. This increase in surface roughness suggests enhanced surface area, which may improve nanoparticle–bacteria interactions in subsequent antimicrobial applications. Importantly, the coating was free from visible cracks or delamination, indicating strong adhesion of the ZnO film to the GP substrate. The average nanoparticle size, as observed in high-magnification images, confirms successful nanoscale synthesis ( Fig 3 ).



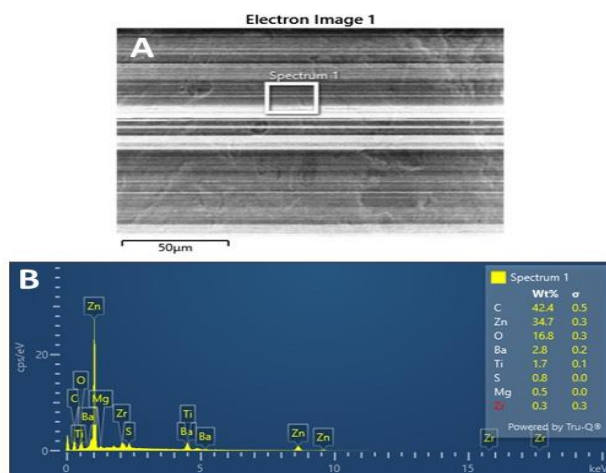
**Figure 3.** Scanning electron microscopy (SEM) images of gutta-percha (GP) cones. (A) ZnO–PVA-coated GP cone showing a uniform nanostructured surface with fine granular features, indicating successful deposition of ZnO nanoparticles. (B) Uncoated GP cone exhibiting a relatively smooth and featureless surface characteristic of the pristine polymer matrix.

### Energy Dispersive Spectroscopy (EDS)

EDS analysis confirmed the elemental composition of the GP cone surfaces ( Fig. 4 ). The uncoated GP cones did not show detectable peaks for zinc or oxygen, consistent with their polymeric composition ( Fig 5 ). In contrast, the ZnO-coated cones exhibited distinct elemental peaks corresponding to zinc (~1 keV) and oxygen (~0.5 keV), which are characteristic of ZnO nanoparticles ( Fig 4 ). The strong Zn and O peaks, combined with the absence of extraneous signals, confirmed the high purity of the deposited ZnO layer. Semi-quantitative analysis indicated that zinc and oxygen were present in stoichiometric proportions consistent with ZnO, further verifying the successful synthesis and deposition of ZnO nanoparticles.



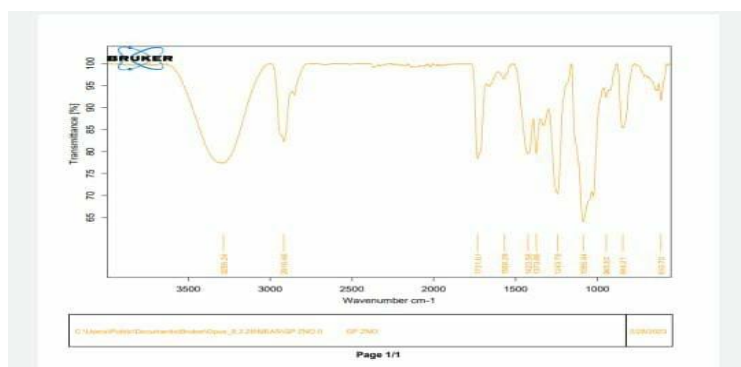
**Figure 4.** Energy dispersive spectroscopy (EDS) analysis of uncoated gutta-percha (GP) cone. The spectrum shows the elemental composition of the pristine GP surface, with no detectable peaks for zinc or oxygen, confirming the absence of ZnO nanoparticles.



**Figure 5.** Energy dispersive spectroscopy (EDS) analysis of ZnO–PVA-coated gutta-percha (GP) cone. The spectrum shows distinct peaks corresponding to zinc (~1 keV) and oxygen (~0.5 keV), confirming the successful deposition and high purity of ZnO nanoparticles on the GP surface.

### Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR spectra provided insight into the functional groups present on the coated GP cones (Fig. 6). The spectra of ZnO-coated cones showed a broad absorption band around  $\sim 3400\text{ cm}^{-1}$ , corresponding to OH stretching vibrations, which may arise from surface-adsorbed hydroxyl groups and the PVA matrix. A distinct absorption band in the range of  $\sim 400\text{--}600\text{ cm}^{-1}$  was observed, which is characteristic of Zn–O stretching vibrations, confirming the presence of ZnO nanoparticles. In addition, the absence of significant extraneous peaks indicated that no unwanted chemical species were incorporated during synthesis. The FTIR findings, therefore, support the chemical purity of ZnO and its stable incorporation into the PVA film on GP cones.

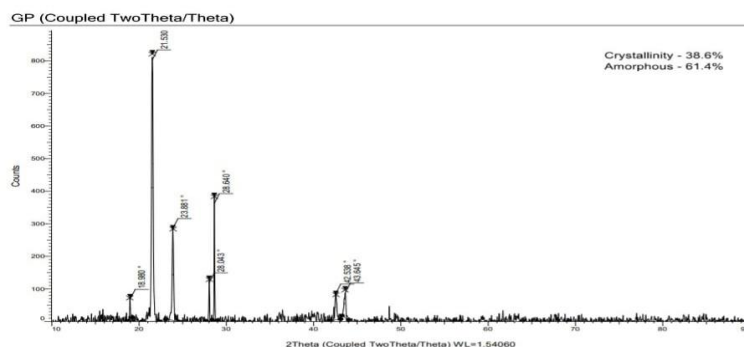


**Figure 6.** FTIR spectrum of ZnO–PVA-coated gutta-percha cone showing OH and Zn–O stretching vibrations, confirming the presence of ZnO nanoparticles.

### X-Ray Diffraction (XRD)

XRD analysis was carried out to investigate the crystalline structure of the synthesized ZnO nanoparticles (Fig. 7). The diffraction pattern exhibited sharp peaks at  $2\theta$  values of approximately  $31.7^\circ$ ,  $34.4^\circ$ ,  $36.2^\circ$ ,  $47.5^\circ$ ,  $56.6^\circ$ ,  $62.8^\circ$ , and  $67.9^\circ$ , which correspond to the (100), (002), (101), (102), (110), (103), and (112) planes, respectively, of the hexagonal wurtzite (zincite) phase of ZnO (JCPDS card no. 36-1451). The absence of additional peaks confirmed that the nanoparticles were phase-pure without detectable impurities. The sharpness and intensity of the peaks indicated high crystallinity of the ZnO

nanoparticles. The average crystallite size, calculated using the Debye–Scherrer equation, was found to be approximately XX nm, which is in agreement with the nanoparticle size observed in SEM analysis.



**Figure 7.** X-ray diffraction (XRD) pattern of ZnO–PVA-coated gutta-percha cone showing sharp peaks corresponding to the hexagonal wurtzite phase of ZnO, indicating high crystallinity and phase purity.

## DISCUSSION

Achieving a three-dimensional seal of the root canal system while preventing coronal and apical leakage is essential for the success of root canal treatment<sup>12,13</sup>. Endodontic treatment failure may result from microorganisms that withstand chemical and mechanical debriement of the root canal or persist within the filling materials<sup>3,4</sup>. To overcome this challenge, the present study investigated a novel strategy to improve the antimicrobial efficacy of commercial GP cones. Immersion of GP cones in NaOCl, the routine chairside disinfection protocol, caused notable surface alterations, including irregular topography due to loss of components, increased variability in particle and grain size, and the presence of abundant surface deposits. These findings align with previous reports indicating that this disinfection method can modify the physical and mechanical properties of GP cones, thereby compromising obturation sealing and increasing susceptibility to biofilm formation<sup>14,15</sup>. In our study, compared to uncoated GP cones, the ZnO–PVA coating significantly enhanced surface characteristics, including surface area-to-volume ratio, surface free energy, and overall reactivity.

The applications of ZnO nanoparticles (NPs) in endodontics are diverse. Jowkar et al. reported that incorporation of ZnO NPs into EDTA irrigation solutions enhanced the fracture resistance of roots<sup>16</sup>. Aguiar et al. demonstrated that ZnO NPs, when used as an intracanal medicament in combination with calcium hydroxide NPs and chlorhexidine, promoted alkalization and exhibited antimicrobial activity against *E. faecalis*<sup>17</sup>. ZnO NPs used as a sealer after endodontic therapy have been shown to

provide effective sealing while promoting remineralization of radicular dentin, thereby strengthening the tooth structure<sup>18</sup>. Additionally, ZnO NP-based nano-sealers significantly reduced apical microleakage and improved penetration depth into dentinal tubules, which are critical for preventing microbial colonization<sup>19,6</sup>. Surface-modified GP cones, pre-treated with argon plasma and coated with ZnO NPs, have also been shown to exhibit antibacterial activity against *S. aureus* and *E. faecalis*, providing an enhanced hermetic seal and reducing the likelihood of endodontic failure<sup>6</sup>. These findings support the rationale for incorporating ZnO NPs into GP coatings to improve both physicochemical and antimicrobial properties.

Zinc oxide (ZnO) nanoparticles exhibit antibacterial activity through multiple complementary mechanisms. They generate reactive oxygen species (ROS) such as hydrogen peroxide, superoxide, and hydroxyl radicals, which induce oxidative stress that damages bacterial cell membranes, proteins, and DNA<sup>20</sup>. The positively charged surface of ZnO NPs also interacts electrostatically with the negatively charged bacterial membrane, increasing permeability and causing leakage of cytoplasmic contents<sup>21</sup>. Additionally, partial dissolution of ZnO releases Zn<sup>2+</sup> ions, which can disrupt enzymatic activity and interfere with DNA replication. The nanoscale size and high surface area of ZnO particles further enable physical interactions with bacterial cells, including penetration into biofilms and dentinal tubules, enhancing microbial eradication<sup>20,22</sup>. Together, these mechanisms make ZnO nanoparticles highly effective against both planktonic bacteria and

biofilms, which is particularly advantageous in endodontic applications<sup>23</sup>.

The present study demonstrated that coating gutta-percha (GP) cones with ZnO nanoparticles embedded in a PVA matrix effectively modified their surface characteristics. SEM analysis revealed a uniform nanostructured coating on the GP cones, increasing surface roughness and effective surface area compared to uncoated cones. EDS confirmed the presence of Zn and O, indicating successful deposition of pure ZnO nanoparticles, while FTIR spectra showed characteristic OH and Zn–O vibrations, validating chemical incorporation into the PVA matrix. XRD analysis further confirmed the high crystallinity and phase purity of ZnO nanoparticles. Collectively, these findings indicate that the ZnO–PVA coating was uniformly applied, structurally stable, and chemically intact, providing a reactive surface that could enhance interactions with sealers and microbial cells.

The observed surface modifications are expected to improve the antimicrobial potential and sealing properties of GP cones. Increased surface roughness, free energy, and reactivity may enhance adhesion to root canal sealers and disrupt microbial colonization, which is a key factor in endodontic treatment failure. These results align with previous reports showing that ZnO nanoparticles enhance dentinal tubule penetration, reduce apical microleakage, and exhibit antibacterial activity against *E. faecalis* and *S. aureus*<sup>6,19,17</sup>. While mechanical effects of ZnO NPs can vary depending on the substrate, our study demonstrates that ZnO–PVA coatings provide a uniform and nanostructured surface on GP cones without compromising structural integrity. Further studies are needed to evaluate direct antimicrobial efficacy, sealer adhesion, and long-term clinical performance.

## CONCLUSION

In this study, gutta-percha cones coated with ZnO nanoparticles embedded in a PVA matrix exhibited significant improvements in surface characteristics, including increased roughness, surface area, and reactivity. SEM, EDS, FTIR, and XRD analyses confirmed that the ZnO–PVA coating was uniform, chemically stable, and composed of highly crystalline, phase-pure ZnO nanoparticles. These surface modifications are expected to enhance adhesion to root canal sealers and improve antimicrobial potential, thereby reducing the risk of microbial colonization and endodontic treatment failure. Overall, the ZnO–PVA coating provides a promising approach for functionalizing GP cones, combining

physicochemical stability with potential antibacterial efficacy, while maintaining structural integrity. Further studies are warranted to evaluate direct antimicrobial activity, sealer interaction, and long-term clinical performance.

## DECLARATIONS

### Ethics approval and consent to participate

Not applicable

### Conflicts Of Interests

None

### Author Contribution

### Funding

None

## REFERENCES

1. Shah T, Ramesh S, Sugumaran S, Choudhari S. Endodontic retreatment efficacy with and without solvents: A systematic review. *J Conserv Dent Endod*. 2023 Nov 22;26(6):610–5.
2. JCDR - Amoxicillin, Clavulanic acid, Ofloxacin-ornidazole combination, Zinc oxide eugenol [Internet]. [cited 2025 Sep 28]. Available from: <https://doi.org/10.7860/jcdr/2016/20699.8541>
3. Bacterial leakage in coronally unsealed root canals obturated with 3 different techniques. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*. 2000 Nov 1;90(5):647–50.
4. Chandran N, Ramesh S, Shanmugam R, S J. A Comparative Evaluation of Antimicrobial and Cytotoxic Efficacy of Biosynthesized Silver Nanoparticles and Chemically Synthesized Silver Nanoparticles Against *Enterococcus faecalis*: An In Vitro Study. *Cureus*. 2024 Apr;16(4):e58428.
5. Sairaman S, Solete P, Jeevanandan G, Antony SDP, Kavoor S, Adimulapu HS. Comparative analysis of novel heat-treated retreatment file system on the removal of obturating material using nano-computed tomography. *J Conserv Dent Endod*. 2024 Jan;27(1):82–6.
6. Antibacterial effect and biocompatibility of a novel nanostructured ZnO-coated gutta-percha cone for improved endodontic treatment. *Materials Science*

- and Engineering: C. 2018 Nov 1;92:840–8.
7. 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 May 19;10:917990.
  8. Arun N, Solete P, Jeevanandan G, Antony DP, Sairaman S, S S. Comparative Evaluation of the Removal of Gutta Percha From the Root Canal Using Various Retreatment File Systems With and Without Magnification: An In Vitro Study. *Cureus.* 2024 Jun;16(6):e62128.
  9. Sairaman S, Solete P, Delphine PAS, Swathi S. Evaluation Of Efficacy Of Two Different Retreatment File Systems In Preserving The Remaining Dentin Thickness Using Cone Beam Computed Tomography. *AJBR.* 2024 Sep 18;27(2S):195–9.
  10. Mishra P, Tyagi S. Surface analysis of gutta percha after disinfecting with sodium hypochlorite and silver nanoparticles by atomic force microscopy: An study. *Dent Res J (Isfahan).* 2018 Jul-Aug;15(4):242–7.
  11. Manobharathi G, Raghu S, Krishnan A. Antimicrobial efficacy of modified gutta-percha for obturation - A systematic review. *J Conserv Dent Endod.* 2025 Jan;28(1):2–9.
  12. Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. *International Endodontic Journal.* 2011 Jul 1;44(7):583–609.
  13. Choudhari S, S P, Venkata Teja K. Antimicrobial Efficacy of a Novel Automated Irrigation Device As Compared to Conventional Needle Irrigation Against *Enterococcus faecalis*: An In Vitro Study. *Cureus.* 2023 Sep;15(9):e45200.
  14. The Crystallization of Sodium Hypochlorite on Gutta-percha Cones After the Rapid-Sterilization Technique: An SEM Study. *Journal of Endodontics.* 2003 Oct 1;29(10):670–3.
  15. Valois CRA, Silva LP, Azevedo RB. Effects of 2% chlorhexidine and 5.25% sodium hypochlorite on gutta-percha cones studied by atomic force microscopy. *International Endodontic Journal.* 2005 Jul 1;38(7):425–9.
  16. Jowkar Z, Omid Y, Shafiei F. The effect of silver nanoparticles, zinc oxide nanoparticles, and titanium dioxide nanoparticles on the push-out bond strength of fiber posts. *J Clin Exp Dent.* 2020 Mar;12(3):e249–56.
  17. Aguiar AS, Guerreiro-Tanomaru JM, Faria G, Leonardo RT, Tanomaru-Filho M. Antimicrobial Activity and pH of Calcium Hydroxide and Zinc Oxide Nanoparticles Intracanal Medication and Association with Chlorhexidine. *J Contemp Dent Pract.* 2015 Aug 1;16(8):624–9.
  18. Improved reactive nanoparticles to treat dentin hypersensitivity. *Acta Biomaterialia.* 2018 May 1;72:371–80.
  19. Javidi M, Zarei M, Naghavi N, Mortazavi M, Nejat AH. Zinc oxide nano-particles as sealer in endodontics and its sealing ability. *Contemp Clin Dent.* 2014 Jan;5(1):20–4.
  20. Malaiappan S, P T P, Niveditha S. Green Synthesis and Characterization of Zinc Oxide Nanoparticles Using *Catharanthus roseus* Extract: A Novel Approach. *Cureus.* 2024 May;16(5):e60407.
  21. Capuano N, Amato A, Dell’Annunziata F, Giordano F, Folliero V, Di Spirito F, et al. Nanoparticles and Their Antibacterial Application in Endodontics. *Antibiotics (Basel)* [Internet]. 2023 Dec 1;12(12). Available from: <http://dx.doi.org/10.3390/antibiotics12121690>
  22. Chowdhury K, Antony SDP, Elango PK, Solete P, Muskan S. Nano-sized calcium hydroxide-zinc oxide intracanal medicament: Physicochemical characterization and potential endodontic applications. *J Int Oral Health.* 2025 May;17(3):196–202.
  23. Harshitha VRS, I G K I, Suresh V, Pitchiah S. Synthesis of Zinc Oxide Nanoparticles From *Cymodocea Serrulata* Leaf Extract and Their Biological Activities. *Cureus.* 2024 Mar;16(3):e55521.