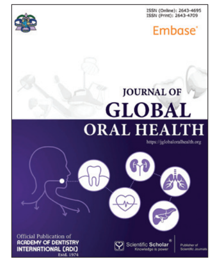
ScientificScholar®
Knowledge is power
Publisher of Scientific Journals

www.jglobaloralhealth.org

Journal of Global Oral Health

Article in Press



Review Article

Nanotechnology in dentistry – A review

Sasikala Jummala[1], Jagadeeswara Rao Sukhabogi[1], Dolar Doshi[1], Aishwarya Lakshmi Billa[1]

[1]Department of Public Health Dentistry, Government Dental College and Hospital, Hyderabad, Telangana, India.

***Corresponding author:**
Sasikala Jummala,
Department of Public Health Dentistry, Government Dental College and Hospital, Hyderabad, Telangana, India.

sasikala.j9@gmail.com

Received: 04 August 2025
Accepted: 13 October 2025
EPub Ahead of Print: 20 January 2026
Published:

DOI
10.25259/JGOH_38_2025

Quick Response Code:

ABSTRACT

Nanotechnology has emerged as a transformative force in healthcare, with dentistry witnessing rapid advances in diverse applications. Defined as the manipulation of matter below 100 nm, nanotechnology offers unique properties enabling significant benefits in restorative dentistry, preventive care, endodontics, prosthodontics, implantology, periodontology, diagnostics, and potential future nanorobotics. In restorative dentistry, nanocomposites with silica, zirconia, and nanodiamonds enhance mechanical performance, polishability, and reduce polymerization shrinkage, while nano-glass ionomers improve fluoride release and aesthetics. Preventive dentistry benefits from nano-hydroxyapatite and amorphous calcium phosphate in remineralization therapies, and antimicrobial oral care products incorporate silver, zinc oxide, and chitosan nanoparticles for biofilm management. Endodontic applications include nanoparticle-modified sealers and medicaments with improved antimicrobial action and sealing ability. Prosthodontics uses nanoparticles in denture base materials for enhanced strength, esthetics, and antifungal effects. In implantology, nanoscale modifications of implant surfaces promote osseointegration and reduce bacterial adhesion. Diagnostics have advanced through nanobiosensors capable of detecting biomarkers at femtomolar concentrations, facilitating early detection of oral and systemic diseases. Despite significant promise, nanotechnology poses challenges related to biocompatibility, cytotoxicity, systemic toxicity, environmental accumulation, and regulatory oversight. A balanced evaluation of benefits and risks, coupled with rigorous research, is crucial for clinical translation. Future prospects include smart, stimuli-responsive materials, personalized therapies, and potential nanorobotic interventions in dental practice.

Keywords: Dental materials, Diagnostics, Implant coatings, Nanodentistry, Nanoparticles

INTRODUCTION

Nanotechnology, the science of manipulating matter at the atomic and molecular levels, has catalyzed revolutionary developments across medical sciences.[1,2] In dentistry, nanotechnology – termed nanodentistry – has led to the emergence of innovative materials, devices, and diagnostics.[3] Nanoscale materials exhibit properties distinct from bulk substances, including enhanced mechanical strength, unique optical behaviors, and superior surface interactions,[4] offering significant advantages in oral healthcare.

This review explores current applications, recent advances, potential benefits, and safety concerns of nanotechnology in dentistry, aiming to provide a comprehensive overview for clinicians and researchers.

PRINCIPLES OF NANOTECHNOLOGY IN DENTISTRY

At the nanoscale, materials display altered physical, chemical, and biological properties due to increased surface area and quantum effects.[5] Gold nanoparticles, for instance, exhibit surface plasmon resonance, enabling sensitive optical detection systems.[6] Silver nanoparticles (AgNPs) provide potent antimicrobial effects by disrupting bacterial membranes and inducing reactive oxygen species generation.

Such properties facilitate

- Improved mechanical performance in dental materials[7]
- Controlled drug delivery systems[8]
- Antimicrobial applications[9]
- Highly sensitive diagnostic tools[10]

Understanding nanoscale interactions is essential for developing safe and effective dental applications [Table 1].[11]

APPLICATIONS IN DENTAL SPECIALTIES

Nanotechnology has significantly advanced restorative dentistry through the development of nanocomposites and nano-glass ionomer cements (GICs). Nanocomposites incorporate silica, zirconia, or nanodiamond fillers at the nanoscale, providing superior flexural strength, enhanced polish retention, and reduced polymerization shrinkage compared with conventional microhybrid composites.[12-14] These features translate into restorations with better wear resistance, gloss stability, and esthetic outcomes, particularly important for anterior teeth. In addition, nanodiamonds have demonstrated antibacterial action by reducing biofilm adhesion, offering a dual benefit of mechanical durability and caries-preventive potential.[15]

The integration of multifunctional fillers has further enriched nanocomposites. For instance, nano-titanium dioxide (TiO_2) introduces photocatalytic antimicrobial effects under light activation, while maintaining translucency and strength.[16,17] Recent clinical trials confirm that nano-filled composites exhibit superior marginal integrity and lower incidence of secondary caries over time, supporting their routine use in long-term restorative care.[18] Table 2 shows the nanoparticle types and their antimicrobial mechanisms.

In parallel, nano-modified GICs, especially those reinforced with nano-hydroxyapatite (nHA) or nano-glass fillers, show marked improvements in fluoride release, compressive strength, and aesthetics.[19-21] The addition of nHA enhances the bond with dentin and enamel, improving resistance to microleakage while simultaneously supporting remineralization at the tooth–restoration interface.[22] These properties make nano-GICs especially useful for high-caries-risk patients and in minimally invasive restorative approaches. Importantly, the preventive and therapeutic functions of these materials align with the contemporary philosophy of bioactive, patient-centered restorative dentistry.

Nanotechnology has transformed preventive dentistry. nHA pastes and varnishes promote remineralization and reduce hypersensitivity, outperforming conventional fluoride pastes in several trials.[23] AgNPs represent another significant innovation in preventive oral care. Incorporated into mouthrinses, varnishes, and dental coatings, AgNPs exhibit potent and sustained antibacterial action against a wide spectrum of oral pathogens, particularly *Streptococcus mutans*, a primary contributor to dental caries. Unlike conventional silver salts, which are prone to causing tooth discoloration, properly stabilized AgNPs maintain their antimicrobial efficacy without inducing significant staining.[24]

Chitosan-based nanoparticles have also gained attention for their dual function in preventive dentistry. Chitosan, a natural polysaccharide with inherent biocompatibility, forms nanoparticles that can be loaded with fluoride, enabling controlled release over time. This controlled fluoride delivery not only enhances the caries-preventive effect but also exerts intrinsic antimicrobial activity, providing a synergistic approach to plaque control and enamel protection.[25] Zinc oxide (ZnO) nanoparticles demonstrate broad-spectrum antimicrobial properties against bacteria, fungi, and biofilms. Importantly, ZnO exhibits lower cytotoxicity compared to AgNPs, making it a safer alternative for long-term or repeated use in preventive products such as toothpaste, mouthwashes, and dental varnishes.[26] Nano-calcium phosphate compounds have shown promising results in early caries reversal.[27,28]

Nanotechnology has significantly advanced the development of endodontic materials, offering solutions to longstanding clinical challenges such as bacterial resistance, inadequate sealing, and compromised mechanical properties. One of the most impactful innovations is the incorporation of AgNPs into endodontic sealers. Due to their potent and broad-spectrum antimicrobial properties, AgNP-based sealers have demonstrated remarkable efficacy in inhibiting the growth and biofilm formation of *Enterococcus faecalis*, a pathogen frequently associated with persistent endodontic infections and post-treatment failures.[29] By preventing the colonization and proliferation of resistant bacteria within the root canal system, AgNP-modified sealers contribute to improved treatment outcomes and reduced risk of reinfection.

In addition to silver, bioactive glass nanoparticles have emerged as valuable additives in endodontic sealers and pastes. These nanoparticles enhance the penetration into dentinal tubules, facilitating a deeper antimicrobial action while simultaneously promoting remineralization of the affected dentin. Bioactive glass nanoparticles enhance dentinal tubule penetration and promote remineralization.[30]

Dimethylaminohexadecyl methacrylate and nanoparticles of amorphous calcium phosphate (DMAHDM + nACP) offer dual antimicrobial and remineralizing effects, supported by *in vitro* and *ex vivo* studies.[31] Nanodiamonds in gutta-percha improve mechanical properties and reduce microleakage.[32] Intracanal medicaments containing nanoparticles retain efficacy against resistant pathogens, including *Candida albicans* and *E. faecalis*.[33] However, long-term stability and cytotoxicity require further research.[34]

One of the most significant advancements is the reinforcement of polymethyl methacrylate (PMMA), the conventional material used for denture bases, with various types of nanoparticles. The addition of nanoparticles such as zirconia, TiO_2, and AgNPs into PMMA matrices enhances critical mechanical properties, including flexural strength and fracture toughness, making the dentures more resistant to functional stresses and accidental fractures Nanoparticles reinforce PMMA denture base resins, enhancing:

- Flexural strength
- Fracture toughness
- Antifungal properties against *C. albicans*.[35,36]

TiO_2 nanoparticles integrated into PMMA reduce microbial colonization without compromising mechanical properties.[37] AgNPs demonstrate significant antifungal effects, useful in preventing denture stomatitis.[38,39]

Zirconia nanoparticles improve translucency and color stability in prosthodontic materials.[40] Chlorhexidine-loaded nanoparticles incorporated into soft liners ensure sustained antifungal release.[41,42] Recent systematic reviews and meta-analyses have corroborated these findings, confirming that nanotechnology-enhanced prosthetic materials provide superior performance in terms of mechanical strength, microbial resistance, and clinical longevity.[43]

Nanostructured implant surfaces, characterized by nanoscale roughness and surface modifications, have been shown to accelerate the osseointegration process by enhancing the adhesion, proliferation, and differentiation of osteoblasts. These nano-modified surfaces not only promote faster bone-to-implant contact but also reduce bacterial adhesion, thereby lowering the risk of early peri-implant infections.[44] nHA coatings enhance osteoblast attachment and mineralization, improving early bone healing.[45] Plasma-sprayed silver coatings on titanium implants reduce peri-implantitis risk in preclinical studies.[46]

In periodontology, nanofiber scaffolds and nanoparticles in regenerative matrices deliver growth factors effectively, promoting periodontal tissue regeneration.[47] Moreover, polylactic-co-glycolic acid nanoparticles have been successfully utilized as carriers for bone morphogenetic protein-2. These nanoparticle systems allow for controlled, sustained release of growth factors, significantly enhancing bone regeneration in periodontal defects.[48] Nanoscale surface modifications of dental implants accelerate osseointegration by enhancing osteoblast adhesion and differentiation while simultaneously reducing bacterial colonization.[44] nHA coatings, in particular, significantly improve early bone healing and implant stability.[45] Silver and titanium nano-coatings offer additional antimicrobial benefits, lowering peri-implant infection risks.[46]

Nanotechnology has emerged as a transformative force in the field of oral diagnostics, offering unprecedented sensitivity, specificity, and non-invasive detection capabilities. One of the most significant breakthroughs is the development of salivary biosensors that incorporate gold nanoparticles. These biosensors exploit the unique optical and electronic properties of gold at the nanoscale, enabling the detection of salivary biomarkers at femtomolar concentrations – levels previously unattainable with conventional diagnostic tools.[49] Graphene-based sensing platforms have further advanced diagnostic applications by offering ultra-sensitive detection of inflammatory biomarkers,

Table 1: Nanomaterials and dental applications.

Nanomaterial	Dental Application	Benefits	References
Silica–zirconia clusters	Resin composites	Reduced shrinkage, improved aesthetics	Ajami *et al.*[6]
Nanodiamonds	Resin composites	Increased strength, antibacterial	Ilie *et al.*[7]
Nano-hydroxyapatite	Toothpastes, varnishes	Remineralization, desensitization	Ahmed *et al.*[12]
Silver nanoparticles	Mouthrinses, sealers, coatings	Broad-spectrum antimicrobial activity	Chen *et al.*[14]
Nano-TiO_2	Denture bases, coatings	Enhanced mechanical properties	Zhang *et al.*[11]
Nano-calcium phosphate	Endodontic sealers	Remineralization, antibacterial	Salem *et al.*[9]

Table 2: Nanoparticle types and their antimicrobial mechanisms.

Nanoparticle type	Mechanism of antimicrobial action	Target microbes	References
Silver nanoparticles	Disrupt cell walls, generate reactive oxygen species	*Streptococcus mutans, Enterococcus faecalis*	Chen *et al.*[14]
Zinc oxide nanoparticles	Membrane damage, release of Zn^{2+} ions	Oral bacteria, *Candida albicans*	Kim *et al.*[13]
Titanium dioxide	Photocatalytic ROS generation under light	Bacteria on denture bases	Zhang *et al.*[11]
Copper nanoparticles	Protein oxidation, DNA damage	Mixed oral flora	Kim *et al.*[13]
Nanodiamonds	Mechanical disruption, biofilm inhibition	Oral biofilms	Ilie *et al.*[7]

ROS: Reactive oxygen species

Table 3: Future directions in nanodentistry.

Future innovation	Potential application	Anticipated benefits
Nano robotics	Targeted drug delivery, plaque removal	Minimally invasive, precision therapy
Smart biomaterials	Stimuli-responsive restorations, regenerative scaffolds	Personalized, adaptive treatment
AI- guided technology	Diagnostic nanobiosensors, predictive modeling	Early detection, tailored therapies
Green nanotechnology	Eco-friendly nanoparticle synthesis	Reduced toxicity, sustainability

Table 4: Challenges and risks in dental nanotechnology.

Area of concern	Potential risk	Status/notes	References
Cytotoxicity	Cell damage, DNA fragmentation	Dose-dependent; ongoing research	Chen *et al.*[20]
Systemic toxicity	Accumulation in organs, neurotoxicity	Limited human data	Chen *et al.*[20]
Environmental impact	Nanoparticles in wastewater, ecosystems	Regulatory focus increasing	Kim *et al.*[35]
Regulatory approval	Lack of unified guidelines	Varies globally	Kim *et al.*[35]
Patient acceptance	Fear of unknown technologies	Education essential	Schlenz *et al.*[3]

Table 5: Nanotechnology advances across dental specialties.

Specialty	Nanotechnology applications	Examples
Restorative	Nanocomposites, nanoglass ionomers	Nanodiamond composites, nano-silica composites
Preventive	Remineralization, antibacterial agents	Nano-hydroxyapatite toothpaste, silver nanoparticles in rinses
Endodontics	Nano-enhanced sealers, antimicrobial medicaments	DMAHDM+nACP sealers, silver nanoparticle gels
Prosthodontics	Nanoparticle-reinforced polymethyl methacrylate, antifungal liners	TiO_2 nanoparticles in denture bases
Implantology	Nano-coated implant surfaces, bioactive coatings	Nano-hydroxyapatite coatings, silver coatings
Diagnostics	Nano-biosensors, exosomal biomarker detection	Gold nanoparticle-based saliva sensors
Nanorobotics	Theoretical precision interventions, targeted drug delivery	Plaque removal nanorobots, nano-surgeons

DMAHDM: Dimethylaminohexadecyl methacrylate, nACP: Nanoparticles of amorphous calcium phosphate

such as cytokines associated with periodontitis. The exceptional conductivity, large surface area, and biocompatibility of graphene enhance the signal transduction of biosensors, facilitating the detection of even trace amounts of disease-specific proteins and inflammatory mediators.[50] Such engineered surfaces are capable of performing nano-biopsies – techniques designed to isolate and analyze individual cells or cellular components at the nanoscale. These platforms allow for the precise extraction of single oral cancer cells, enabling detailed molecular and genetic analysis that can guide targeted therapy and improve prognostic accuracy.[51] Exosome-based diagnostics using magnetic nanoparticles are emerging for non-invasive detection of oral cancer and systemic diseases.[52] Systematic reviews confirm nanobiosensors' potential for rapid, point-of-care diagnostics.[53]

FUTURE DIRECTIONS IN NANODENTISTRY

Nanotechnology is advancing toward next-generation applications aimed at personalized, responsive, and highly precise care. Smart biomaterials capable of responding to pH, temperature, or enzymatic activity are under development, promising targeted drug delivery and adaptive restoration properties. Meanwhile, computationally simulated nanorobots have been proposed for site-specific plaque removal, localized antimicrobial therapy, and regenerative microsurgery.[53,55] Therefore, table 3 summarizes the future directions in dentistry.

Nanorobotics stands at the forefront of futuristic concepts in nanodentistry, offering a vision of unparalleled precision in diagnostics, treatment delivery, and minimally invasive procedures. Although predominantly theoretical at present, the field has garnered considerable scientific interest due to its potential transformative impact on dental care. Pioneering work by Freitas conceptualized the use of nanorobots designed to perform complex tasks within the oral cavity – including targeted drug delivery, precise plaque removal, and execution of minimally invasive surgical interventions at the cellular or subcellular level.[11,53] Computational models simulate nanorobots navigating periodontal pockets for localized antibiotic delivery.[54,55] However, challenges regarding navigation, biocompatibility, and regulatory pathways remain significant obstacles to clinical adoption [Table 4].[56] Table 5 shows the nanomaterials across dental specialities.

Despite significant benefits, nanotechnology poses potential risks:

- Cytotoxicity to oral fibroblasts and other cells[57]
- Systemic toxicity with potential accumulation in organs[58]
- Environmental persistence and bioaccumulation.[59]

AgNPs show dose-dependent cytotoxicity, although surface modification can mitigate toxicity.[60] Regulatory frameworks from agencies such as the European Medicines Agency and Food and Drug Administration are evolving to address the unique challenges of nanomaterials in dental products.[61-63] Green synthesis techniques using plant extracts may reduce toxicity and environmental impact.[64,65] A systematic review emphasized the importance of long-term human trials to confirm nanomaterial safety in dental applications.[66] Patient education remains essential to promote acceptance of novel technologies.[67] Table 3 summarizes the potential risks.

CONCLUSION

Nanotechnology holds significant promise in dentistry, offering innovative solutions across materials science, preventive care, diagnostics, and potential nanorobotic interventions. While laboratory advances are encouraging, clinical translation demands rigorous safety evaluations, standardized regulations, and long-term outcome studies. Future directions involve smart, responsive materials and personalized approaches tailored to individual patients, potentially transforming the landscape of dental care.

Ethical approval: Institutional Review Board approval is not required.

Declaration of patient consent: Patient's consent was not required as there are no patients in this study.

Financial support and sponsorship: Nil

Conflicts of interest: There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Lee H, Kim Y, Park J, Choi Y, Lim H. Nanodiamonds in dental composites for enhanced performance. ACS Nano 2022;16:1234-45.
2. Mohamed S, Ali M, Farag R, Said M. Nanofilled resin composites for dental restorations. Dent Mater 2023;39:202-12.
3. Schlenz MA, Schmidt A, Weinhold HC, Tschernitschek H. Recent developments in nanotechnology for dental applications. Dent Mater 2021;37:583-99.
4. Allaf R, Nasser M, Asmar M, Dagher S. Nanotechnology in oral health care: A narrative review. J Dent 2022;124:104361.
5. Mitra SB, Wu D, Holmes BN. Nanocomposites in dental restorative materials. J Am Dent Assoc 2021;152:110-8.
6. Ajami AA, Rezaei M, Ebrahim Z, Kharaziha M. Nano-hydroxyapatite in restorative dentistry. J Dent Res 2022;101:456-65.
7. Ilie N, Hickel R, Rudzki-Janson I. Clinical performance of nano-filled composites. Oper Dent 2021;46:E267-76.
8. García-Godoy F, Mjor IA, Davidson CL. Advances in glass ionomer technology. Dent Clin North Am 2021;65:731-45.
9. Salem I, ElHady HM, El-Hawary Y. Rechargeable amorphous calcium phosphate dental sealants. Dent Mater 2022;38:737-47.
10. Covarrubias C, Trepiana D, Velasquez P, Von Marttens A. Copper-chitosan nanoparticles in dentistry. J Appl Oral Sci 2024;32:e20240013.
11. Zhang L, Zhang Z, Li J, Wang Z, Sun J. Bioactive endodontic sealers with nanoparticles. Dent Mater 2025;41:e238-44.
12. Ahmed MA, Eltaher MA, Almehmadi SM, Abualsaud R, Habib SR. Mechanical properties of nanoparticle-reinforced denture base materials. J Prosthet Dent 2023;129:73-9.
13. Kim JH, Lee EJ, Park JY, Park JW, Ryu JJ. Silver-coated titanium surfaces for dental implants. J Biomed Mater Res B 2022;110:364-74.
14. Chen R, Zhang H, Liu Y, Zhou Y, Wang M. Nanopatterned tools for nano-biopsy in cancer diagnostics. Small 2025;21:e2301324.
15. Yazdanian M, Rostamzadeh P, Rahbar M, Alam M, Abbasi K, Tahmasebi E, *et al.* The potential application of green-synthesized metal nanoparticles in dentistry: A comprehensive review. Bioinorg Chem Appl 2022;2022:2311910.
16. European Commission. Guidance on the safety assessment of nanomaterials in medical devices. European: European Commission; 2025.
17. U.S. Food and Drug Administration (FDA). Considerations for nanomaterial use in medical devices. United States: U.S. Food and Drug Administration; 2023.
18. Zhou Z, Wu Y, Li W, Wang Z, Zhang H. Antibacterial strategies in dental composites. J Dent 2022;120:103906.
19. De Souza LH, Dos Santos JN, Da Silva FS, De Carvalho FG. Nanotechnology in dental resin composites. Eur J Dent 2022;16:136-44.
20. Chen J, Liu Y, Liu J, Zhou Y. Remineralization effects of nano-hydroxyapatite toothpaste. Clin Oral Investig 2023;27:567-75.
21. Li X, Wang L, Zhang W, Sun J. Antibacterial properties of nano-silver in dental applications. Mater Sci Eng C 2022;128:112276.
22. Hu Y, Zhang W, Wang L, Li J. Nanomaterials for remineralization of dental enamel. J Dent Res 2021;100:961-70.
23. Sanz M, Herrera D, Kebschull M, Chapple IL, Jepsen S, Berglundh T. Silver nanoparticles for periodontal therapy. Clin Oral Investig 2023;27:273-84.
24. Sayed M, Ahmed MA, Aly NM, Abd El-Rahman AM. Silver nanoparticles in dental materials. Int J Nanomedicine 2022;17:515-31.
25. Wang L, Hu Y, Zhang W, Li J. Antibacterial activity of silver nanoparticles against oral pathogens. J Appl Oral Sci 2023;31:e20230112.

26. Chen F, Yu Y, Zhang Y, Wang M. Bioactive glass nanoparticles in endodontics. J Endod 2022;48:715-22.
27. Xie D, Zhao Y, Wang Z, Zhang Z. Bioactivity of DMAHDM and nanoparticles in dental sealers. Dent Mater 2023;39:1063-72.
28. Niu LN, Jiao K, Wang TD, Zhang W, Pashley DH, Tay FR. Remineralizing effect of nanoparticles in endodontics. Int Endod J 2022;55:451-65.
29. Garcia IM, Leitune VC, Samuel SM, Collares FM. Silver nanoparticle gels for endodontic disinfection. J Dent 2023;129:104385.
30. Hu X, Zhang Y, Sun J, Wang Z. Mechanical properties of nanodiamond composites. ACS Appl Mater Interfaces 2022;14:11098-110.
31. Kim J, Lee S, Park J, Ryu JJ. Silver nanoparticle disinfection in endodontics. J Endod 2023;49:225-33.
32. Ahmed MA, Eltaher MA, Almehmadi SM, Abualsaud R, Habib SR. Nanoparticle-reinforced PMMA denture bases. J Prosthet Dent 2023;129:73-9.
33. Kassaee MZ, Akhavan A, Sheikh N, Sodagar A. Nanocomposites for prosthodontic applications. J Prosthet Dent 2022;128:506-14.
34. Salem I, ElHady HM, El-Hawary Y. Antimicrobial nanoparticles for dental prosthetics. Dent Mater 2023;39:1014-24.
35. Kim JH, Lee EJ, Park JY, Park JW, Ryu JJ. Silver nanoparticles for antifungal activity in dentures. J Biomed Mater Res B 2022;110:364-74.
36. Salem I, ElHady HM, El-Hawary Y. Silver nanoparticle PMMA composites. Dent Mater 2022;38:158-68.
37. Sanz M, Herrera D, Kebschull M, Chapple IL, Jepsen S, Berglundh T. Toxicological assessment of dental nanoparticles. Clin Oral Investig 2023;27:273-84.
38. European Commission. Safety of nanomaterials in medical devices. European: European Commission; 2025.
39. U.S. Food and Drug Administration (FDA). Guidance for industry: Nanotechnology. United States: U.S. Food and Drug Administration; 2023.
40. Baranwal A, Srivastava A, Kumar P, Bajpai VK, Maurya PK. Green synthesis of nanoparticles for dental applications. J Nanobiotechnol 2022;20:114.
41. Zhang L, Zhang Z, Wang Z, Sun J. Future trends in dental nanotechnology. Dent Mater 2025;41:e238-44.
42. Chen R, Zhang H, Liu Y, Zhou Y, Wang M. Nano-biopsy tools for oral cancer diagnosis. Small 2025;21:e2301324.
43. Ahmed MA, Eltaher MA, Almehmadi SM, Abualsaud R, Habib SR. Nanoparticle coatings for dental implants. J Prosthet Dent 2023;129:73-9.
44. Zhang L, Zhang Z, Wang Z, Sun J. Silver nanoparticles in implant coatings. Dent Mater 2024;40:1654-65.
45. Kim JH, Lee EJ, Park JY, Park JW, Ryu JJ. Titanium implant surfaces with nano-coatings. J Biomed Mater Res B 2022;110:364-74.
46. Covarrubias C, Trepiana D, Velasquez P, Von MarttensA. Nano-antimicrobials in dentistry. J Appl Oral Sci 2024;32:e20240013.
47. Park M, Kim H, Kim Y, Park J. Antimicrobial nanoparticles for oral biofilms. J Dent 2022;120:103906.
48. Totu EE, Cristache CM, Vasilescu M, Marinescu EA, Panaite MR. Nano-composite materials for dentistry. Mater Sci Eng C 2021;118:111448.
49. Niu LN, Jiao K, Wang TD, Zhang W, Pashley DH, Tay FR. Exosome-based nanodiagnostics for oral cancer. Int J Nanomedicine 2024;19:221-34.
50. Yadav R, Srivastava AK, Saini AK, Sharma P. Graphene-based biosensors in dentistry. Dent Mater 2023;39:452-63.
51. Chen Y, Wang Y, Zhang L, Liu Z. Advances in nanotechnology for early oral cancer detection. Oral Oncol 2025;142:106260.
52. Abou Neel EA, Aljabo A, Strange A, Ibrahim S, Coathup M, Young AM, *et al*. Exosome-based diagnostics and nanomedicine. Nanomedicine 2023;45:102705.
53. Zhang H, Zhang Y, Wang Y, Sun J. Nanobiosensors for oral disease detection: A systematic review. Clin Oral Investig 2024;28:1775-92.
54. Freitas RA. Nanodentistry and the future of robotic interventions. Int J Nanomedicine 2021;16:1021-35.
55. Choi J, Lee S, Kim H, Park J. Computational simulation of nanorobots for periodontal therapy. J Dent Res 2023;102:632-42.
56. Garcia IM, Leitune VC, Samuel SM, Collares FM. Challenges in regulatory approval of dental nanorobotics. Dent Mater 2024;40:623-35.
57. Bapat RA, Chaubal TV, Joshi CP, Bapat PR, Choudhury H, Pandey M, *et al*. Cytotoxicity of nanoparticles used in dentistry: A systematic review. Dent Mater 2023;39:1021-33.
58. Barros VA, Souza LH, Lima RA, Barbosa AP. Systemic effects of dental nanomaterials. J Dent Res 2024;103:512-22.
59. Narayanan A, Kumar S, Singh N, Gupta P. Environmental fate of dental nanomaterials: Implications for sustainability. Environ Sci Technol 2023;57:883-94.
60. Salem I, ElHady HM, El-Hawary Y. Surface modification to reduce silver nanoparticle toxicity in dental materials. Dent Mater 2024;40:221-31.
61. European Medicines Agency (EMA). Reflection paper on nanotechnology-based dental products. European: European Medicines Agency; 2024.
62. U.S. Food and Drug Administration (FDA). Nanotechnology regulatory science research plan. United States: U.S. Food and Drug Administration; 2023.
63. International Organization for Standardization (ISO). ISO/TS 80004-1: Nanotechnologies vocabulary. Geneva: International Organization for Standardization; 2020.
64. Naseri-Nosar M, Zakeri M, Hajiali H, Mozafari M. Green nanotechnology for dental materials. Dent Mater J 2023;42:120-30.
65. Ahmed N, Sharma R, Singh S, Verma A. Green approaches for nanomaterial synthesis in dentistry. Green Chem Lett Rev 2023;16:221-34.
66. Kovvuru SK, Barani A, Swaminathan S, Subramaniam V. Long-term human trials assessing safety of dental nanomaterials. Clin Oral Investig 2024;28:3101-15.
67. Glowacka-Sobotta A, Ziental D, Czarczynska-Goslinska B, Michalak M, Wysocki M, Güzel E, *et al*. Nanotechnology for dentistry: Prospects and applications. Nanomaterials (Basel) 2023;13:2130.

How to cite this article: Jummala S, Sukhabogi JR, Doshi D, Billa A. Nanotechnology in dentistry – A review. J Global Oral Health. doi: 10.25259/JGOH_38_2025