Review Article

Nanoparticles in Dentistry: A Review

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ABSTRACT

Nanoparticles (NPs) are tiny clusters of atoms, typically measuring between 1 and 100 nanometers, used in various fields, including medicine and dentistry, due to their unique physical, chemical, and biological properties. Nanotechnology, which manipulates these materials at an atomic scale, has propelled advancements in cancer treatment, drug delivery, antimicrobial agents, and tissue engineering. In dentistry, nanoparticles enhance treatments, prevention strategies, and materials like restorative agents and implants, due to their antimicrobial, adhesive, and mechanical properties. The origins of nanotechnology can be traced back to physicist Richard P. Feynman, who envisioned its potential in 1959. Historically, nanoparticles were used in ancient Roman and medieval art, although their effects were not scientifically understood until much later. The use of nanoparticles in dentistry extends from caries prevention and periodontal treatment to dental implants and oral cancer therapies. They help improve disinfection, tissue regeneration, and the mechanical properties of dental materials. However, there are concerns about the potential cytotoxic and genotoxic effects, cost barriers, and inadequate long-term studies on their safety. The disposal of nanomaterials in dental clinics also poses environmental and health challenges, requiring regulated waste management systems.

Keywords: Nanoparticles, Nanotechnology, Dental Applications, Disposal of Nanomaterials, Dentistry.

INTRODUCTION

What are nanoparticles?

Nanoparticles (NPs) are distinct clusters of atoms with numerous medical applications, such as cancer treatment, drug delivery, tissue engineering, regenerative medicine, biomolecule detection, and antimicrobial agents. NPs can be categorized into three main types: organic (including dendrimers, micelles, liposomes, or polymers), inorganic (comprising metal or metal oxide-based particles), and carbon-based (such as fullerenes, graphene, or carbon nanotubes).[1] Nanotechnology marks a significant scientific advancement, propelling humanity into a new age of technological breakthroughs. The term "nano," which comes from the Greek word meaning "dwarf," refers to a scale of one-billionth of a meter. Nanoscale structures typically measure between 1 and 100 nanometers; for comparison, a human hair is about 100,000 nanometers thick, and atoms are approximately 0.1 nanometers in size. Nanotechnology involves manipulating materials at this incredibly small scale, allowing for precise control over their structure and properties. This field focuses on the analysis, fabrication, and development of nanoscale devices, creating materials and systems that possess unique physical, chemical, and biological characteristics distinct from those of larger-scale structures.[2] The conceptual origins of nanotechnology were laid out in 1959 by physicist Richard P. Feynman in his famous talk, "There is plenty of room at the bottom," where he imagined the possibility of manipulating matter at the atomic level. Since then, rapid advancements in both the theoretical and practical dimensions of nanotechnology have emerged, paving the way for revolutionary applications in various fields.[3] Due to their minuscule size, nanoparticles exhibit unique physical, chemical, and biological properties compared to their bulk counterparts, which make them particularly useful in various fields, including medicine and dentistry. Their applications range from drug delivery systems to antimicrobial agents.[4,5]

History

The use of nanoparticles and nanostructures dates back to the 4th century AD, as evidenced by the Romans, who showcased an early example of nanotechnology in the form of the Lycurgus Cup, now part of the British Museum collection. This cup, crafted from dichroic glass, is one of the most remarkable achievements of ancient glassmaking. Dichroic glass refers to glass that exhibits two different colours depending on the lighting conditions.[6] The Lycurgus Cup appears green in direct light but shifts to a red-purple hue when light passes through it. The concept of nanotechnology was first introduced by American physicist and Nobel laureate Richard Feynman in 1959. In 1990, scientists examined the cup using transmission electron microscopy (TEM) to understand its dichroic properties. The colour-changing effect is due to the presence of nanoparticles, ranging from 50 to 100 nanometers in diameter. X-ray analysis revealed that these nanoparticles consist of a silver-gold (Ag-Au) alloy, with a composition of approximately 70% silver and 30% gold, along with about 10% copper, dispersed in a glass matrix. The gold nanoparticles absorb light around 520 nm, resulting in the red colour, while the red-purple hue arises from larger particles. The green colour is attributed to the scattering of light by colloidal dispersions of silver nanoparticles larger than 40 nm. The Lycurgus Cup is now recognized as one of the oldest examples of synthetic nanomaterials. A similar effect is seen in medieval church windows, where luminous red and yellow hues were produced by the fusion of gold and silver nanoparticles into the glass.[7]

Between the 9th and 17th centuries, “luster” ceramic glazes used in Islamic art and later in Europe contained silver, copper, or other nanoparticles, creating a glowing effect. In the 16th century, Italian artisans adopted these techniques to craft Renaissance pottery. They were also influenced by Ottoman methods used to produce "Damascus" Saber blades between the 13th and 18th centuries. These blades incorporated cementite nanowires and carbon nanotubes to enhance their strength, resilience, and sharpness. For hundreds of years, these colours and material properties were intentionally produced, though medieval artists and craftsmen were unaware of the underlying nanotechnology responsible for these effects. In 1857, Michael Faraday explored the preparation and properties of colloidal suspensions of "Ruby" gold. These gold nanoparticles exhibited unique optical and electronic characteristics, making them particularly fascinating. Faraday demonstrated that gold nanoparticles create solutions of different colours depending on lighting conditions, contributing to early research in nanoparticle behavior.[8]

Nanoparticles in Dentistry

Nanoparticles are revolutionizing dentistry through their diverse applications, particularly in antimicrobial treatments, smart materials, and dental implants. Their unique properties enable enhanced performance in various dental procedures, making them a focal point of current research.[9] In dentistry, nanoparticles are utilized across a wide range of treatments due to their antibacterial, adhesive, and mechanical properties. They play a crucial role in restorative materials, endodontic therapies, and oral disease prevention, with their ability to specifically interact with tissues, bacteria, and biofilms offering significant advantages for dental treatments. Nanotechnology is transforming the field through its diverse applications, especially in antimicrobial treatments, smart materials, and dental implants.[10] Silver nanoparticles (AgNPs) are particularly noted for their strong antimicrobial activity, effectively targeting oral pathogens and preventing infections. They are incorporated into dental materials such as acrylic resins and intracanal medications to enhance disinfection and prophylactic outcomes.[11] The development of "smart" nanomaterials, capable of adapting to environmental stimuli such as temperature, pH, or stress, is advancing preventive dentistry and restorations. Carbon nanotubes, with their large surface area and ability to adhere easily to tooth surfaces, are used in teeth fillings and coatings. However, their reactivity can vary based on structure, size, surface, and purity, and under certain conditions, they can induce inflammatory and fibrotic reactions.[12] Graphene, used for teeth coatings and biofilm reduction, is known for its cost-effectiveness, fracture resistance, and low density, but its toxicity is influenced by its shape, size, and oxidative state, with potential metallic impurities post-synthesis raising concerns about variable toxicity responses. Hydroxyapatite (HAp) is employed to reduce dental hypersensitivity, act as a cavity filler, and repair enamel surfaces due to its biocompatibility and similar composition to teeth and bone.[13] However, its nano-sized particles may bind with proteins to form complexes that are destroyed by macrophages, potentially traveling to organs like the lungs and liver, and affecting inflammatory responses and oxidative stress.[14] Zirconia nanoparticles help reduce bacterial adhesion to teeth, providing protection against dental caries, and are effective polishing agents with favourable mechanical properties and low cytotoxicity. Nevertheless, exposure to zirconia nanoparticles has been associated with DNA damage, cellular oxidative stress, and adverse effects such as apoptosis and inhibited cell proliferation.[15] Lastly, silica nanoparticles, used as dental filling agents, polishing materials, and antibacterial agents, are cost-effective and biocompatible with low toxicity, contributing to reduced surface roughness of teeth when used as polishing agents.[16]

Present Uses of Nanoparticles in Dentistry

Nanoparticles have found significant applications in dentistry, especially in the prevention and treatment of various oral diseases due to their unique properties when associated with different materials. For dental caries prevention and treatment, calcium fluoride nanoparticles (CaF2NPs) effectively prevent biofilm formation, inhibit exopolysaccharide production by *Streptococcus mutans*, and promote tooth enamel remineralization. Nanoparticles are utilized in products like toothpaste and oral rinses, enhancing their antibacterial properties and effectiveness against dental caries and periodontal diseases.[17] Silver nanoparticles (Ag NPs) exhibit universal germicidal activities, making them valuable in combating oral infections. The combination with chitosan bio adhesive films increases their residence time in the oral cavity, while chitosan itself exhibits anti-growth and anti-adherence properties against cariogenic bacteria. Nanoparticles, such as bioactive glass nanoparticles (BG-NPs) and chitosan nanoparticles (CS-NPs), promote the regeneration of dental tissues by stimulating the growth and differentiation of stem cells in the dentin-pulp complex.[18] When paired with sodium fluoride, chitosan ensures slow and continuous fluoride release, particularly under acidic conditions, while its combination with glass ionomer cement enhances material resistance, fluoride release, and bactericidal activity. Further associations with titanium oxide nanoparticles (TiO2NPs) provide additional antimicrobial benefits.[19] Copper nanoparticles (CuNPs) also exhibit bactericidal properties, while amelogenin-derived peptide QP5 enhances both antibacterial activity and tooth remineralization. In the treatment of periodontal disease, silver nanoparticles (AgNPs) demonstrate strong antimicrobial efficacy, particularly when combined with azithromycin, clarithromycin, and electro spun nanofibers, which provide excellent antibacterial activity.[20] Similarly, platinum nanoparticles (PtNPs) and bismuth subsalicylate nanoparticles (NPs) are effective against key periodontal pathogens. The use of polylactic-co-glycolic acid (PLGA) nanoparticles combined with curcumin or metformin hydrochloride aids in reducing inflammation, bone loss, and biofilm formation. Nanoparticles also show promise in addressing pulp and periapical lesions, where chitosan, silver, and diamond nanoparticles improve root canal disinfection and lesion size reduction, particularly when combined with agents like EDTA.[21] In the context of peri-implantitis and implant failures, AgNPs and TiO2NPs effectively coat titanium surfaces to prevent bacterial adhesion and promote osseous interface formation. Gold nanoparticles (AuNPs) are especially beneficial in enhancing osteogenic differentiation and influencing bone regeneration.[22] Chitosan, when paired with hyaluronic acid or collagen, improves peri-implant tissue attachment. Advanced imaging techniques using nanoparticles enable early and precise detection of dental diseases, improving diagnostic accuracy.[23] For dental prosthesis failures, incorporating zirconium oxide, silica, zinc oxide, and titanium dioxide nanoparticles into PMMA (polymethyl methacrylate) enhances the material's mechanical properties, such as tensile strength, microhardness, and thermal stability, though some nanoparticles may decrease impact strength. Chitosan, when used in mouthwash, curcumin, or miconazole-based formulations, is effective against oral candidiasis and denture stomatitis, reducing symptoms and fungal growth. In the treatment of head, neck, and oral cancer, nanoparticles like solid lipid nanoparticles (SLNs) combined with drugs like paclitaxel, ascorbic acid, and doxorubicin show promise in enhancing apoptosis and treating oral squamous cell carcinoma.[7,16] Diagnostic applications of carbon and AuNPs in cancer also offer enhanced sensitivity in various analyses, with AuNPs proving particularly useful in combination with X-ray irradiation for inducing apoptosis. Finally, liposomes have been explored for their effectiveness in treating hyposalivation by improving water adsorption and stability when combined with pectin, alginate, or chitosan.[24]

Limitations

The use of nanoparticles in dentistry offers numerous advantages, such as improved antimicrobial activity, enhanced mechanical properties of restorative materials, and effective prevention and treatment of oral diseases. However, their application is not without significant limitations and risks. One of the primary concerns is the potential toxicity and health risks associated with nanoparticles.[25] Studies indicate that nanoparticles can induce cytotoxic and genotoxic effects, which may result in adverse health reactions, including damage to cells and genetic material.[26] Exposure to nanoparticles, especially through inhalation or ingestion during dental procedures, poses risks to vital organs such as the lungs, liver, and kidneys. Furthermore, insufficient research on the long-term effects of nanoparticles raises additional concerns. For example, while silver-based biomaterials are frequently used in dental applications for their antimicrobial properties, there is a lack of long-term clinical studies evaluating their durability and biocompatibility.[27] This gap in knowledge extends to understanding the precise mechanisms by which nanoparticles interact with tissues, as well as the long-term responses of biological systems to these materials, necessitating further investigation. In addition to health and safety concerns, the cost of nano dental products presents a significant barrier to their widespread use.[28] The high-cost limits accessibility, particularly in low-resource settings, which can hinder the adoption of these advanced materials in dental practices. While the potential of nanoparticles in enhancing dental treatments is promising, the associated health risks, insufficient research on long-term effects, and high costs underscore the importance of cautious and well-regulated implementation in clinical practice.[29] Comprehensive research and safety assessments are crucial to ensure that the benefits of nanoparticle technology can be realized without compromising patient safety or accessibility.

Disposal of nano materials in dental clinic

The disposal of nanomaterials in dental clinics is a growing concern due to their unique properties and potential health hazards. As nanotechnology advances in dentistry, understanding the impact of nanomaterial disposal is crucial for ensuring both safety and compliance with health regulations.[30] The generation of nano waste has increased significantly with the widespread use of nanomaterials in pharmaceuticals, diagnostics, and medical devices. This leads to a growing accumulation of nanomaterials in dental settings.[31] Current disposal methods, such as incineration and filtration, may not effectively manage the risks associated with nano waste, as these processes can release harmful nanoparticles into the environment. To address these challenges, innovative solutions like metal nanoparticles and nano filters have been proposed to improve the degradation and removal of toxic hospital waste.[32] From a regulatory and environmental perspective, the lack of clear policies governing nanomaterial disposal complicates effective waste management. The potential for bioaccumulation and long-term environmental effects underscores the need for comprehensive regulatory frameworks tailored to the management of nano waste.[33] Health risks associated with improper nanomaterial disposal are also significant, as nanoparticles can exhibit cytotoxic and genotoxic properties.[34] Their small size enables them to penetrate biological barriers, which may result in unintended health consequences. Current regulations for hazardous waste disposal may not adequately address the specific challenges posed by nanomaterials in dental practices, highlighting the need for updated guidelines that specifically target the safe disposal of these materials.[35] Looking forward, research is essential to develop safe and effective disposal methods, as well as to evaluate the environmental impact of dental nanomaterials. As the integration of nanotechnology in dentistry continues to grow, it must be accompanied by thorough safety assessments to mitigate the risks associated with the disposal of nanomaterials.[36]

CONCLUSION

In conclusion, while nanoparticles hold great promise in revolutionizing dental practices, ongoing research is essential to address safety concerns and optimize their applications in clinical dentistry. Nanoparticles, due to their unique properties, can enhance various aspects of dental treatment, such as improving drug delivery, enhancing the effectiveness of dental materials, and enabling precise imaging and diagnostics. Their ability to modify physical and chemical interactions at the nanoscale opens up opportunities for more effective treatments, such as targeted therapies for oral diseases and improved biocompatibility of dental implants. Additionally, regulatory frameworks must evolve to accommodate the unique challenges posed by nanotechnology. Policymakers and regulatory bodies should work closely with researchers to establish guidelines that ensure the safe use of nanoparticles in dental applications while encouraging innovation and development in this promising field.

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REFERENCES

1. Rudramurthy GR, Swamy MK. Potential applications of engineered nanoparticles in medicine and biology: An update. J Biol Inorg Chem. 2018;23(5):1185–1204.
2. Anu Mary Ealia S, Saravanakumar MP. A review on the classification, characterisation, synthesis of nanoparticles and their application. IOP Conf Ser Mater Sci Eng. 2017; 263:032019.
3. Deb S, et al. Nanotechnology Applications in Dentistry. J Oral Sci. 2024;64(3):112–124.
4. Priyadarsini S, Mukherjee S, Mishra M. Nanoparticles used in dentistry: A review. J Oral Biol Craniofac Res. 2018;8(1):58–67.
5. Vasiliu S, Racovita S, Gugoasa I, Lungan MA, Popa M, Desbrieres J. The Benefits of Smart Nanoparticles in Dental Applications. Int J Mol Sci. 2021;22(5):2585. doi:10.3390/IJMS22052585.
6. Liu F, Deng W. Role of Nanoparticles in Restorative Dentistry. Dent Oral Health J. 2024;12(1):45–58.
7. Use of Nanoparticles as Materials to Prevent Dental and Oral Diseases. J Adv Dent Res. 2024;38(4):234–246.
8. Mitra S, et al. An Application of Nanotechnology in Advanced Dental Materials. J Am Dent Assoc. 2003;134(10):1382–1390.
9. Allaker RP, Ren G. Potential Impact of Nanotechnology on the Control of Oral Biofilms. J Nanobiotechnol. 2008;6(3):1–15.
10. Saravana KR, Vijayalakshmi R. Nanotechnology in dentistry. Indian J Dent Res. 2006;17(2):62–65.
11. Kamath V, Mukherjee P, Swapna BV, Kamath M. Nanodentistry: Present and Future. Res J Pharm Technol. 2021;14(8):1135–1142. doi:10.52711/0974-360X.2021.00689.
12. Pushpalatha C, et al. Nanomaterials for the Management of Multidisciplinary Dental Sciences and Applications. Res Biomed Mater Sci. 2021; 10:132–150. doi:10.1007/978-3-030-67223-2_10.
13. Raju R. Nanotechnology in interdisciplinary dentistry. Indian J Med Sci. 2020;72(3):45–56. doi:10.25259/IJMS_74_2020.
14. Moothedath M, et al. Role of nanotechnology in dentistry: Systematic review. J Int Soc Prev Community Dent. 2019;9(2):89–95. Doi: 10.4103/JISPCD.JISPCD_223_19.
15. Schleyer TL. Nanodentistry: Fact or fiction? J Am Dent Assoc. 2000;131(11):1567–1568.
16. Duke ES. Has dentistry moved into the nanotechnology era? Compend Contin Educ Dent. 2003;24(4):380–382.
17. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc. 2003;134(10):1382–1390.
18. Ozak ST, Ozkan P. Nanotechnology and dentistry. Eur J Dent. 2013;7(1):145–151.
19. Use of Nanoparticles as Materials to Prevent Dental and Oral Diseases. Futur Dent Sci. 2024;38(4):8795.
20. Pecci-Lloret M, et al. Use of Nanoparticles in Regenerative Dentistry: A Systematic Review. Biomimetics. 2024;9(4):243. doi:10.3390/biomimetics9040243.
21. Deb D, et al. Upsurging nanotechnology in dentistry. BAMS Sci Rev. 2024;3(2):156–165.
22. Temur N, et al. silver nanoparticles in dentistry. Dent Clin North Am. 2024;63(4):123–140. doi:10.1016/b978-0-443-15343-3.00008-5.
23. Yasemin Y. Utilization of Nanomaterials in Prosthetic Dental Treatment. HRU Int J Dent Oral Res. 2023;8(3):145–153. doi:10.61139/ijdor.1270852.
24. Malik S, Waheed Y. Emerging Applications of Nanotechnology in Dentistry. Dent J. 2023;11(11):66. doi:10.3390/dj11110266.
25. Tafti F, et al. Hazards Associated with Nanotechnology in Clinical Dentistry. Cureus. 2023;15(7): e46978. doi:10.7759/cureus.46978.
26. Tsitaishvili L, Gedenidze L. Clinical Aspects and Possibilities of Using Nanoparticles in Modern Dentistry. Int J Sci Res. 2023;8(1):112–118.
27. Karunakaran H, et al. Local and systemic adverse effects of nanoparticles in dental materials. Saudi Dent J. 2023;35(3):145–156. Doi: 10.1016/j.sdentj.2023.08.013.
28. Chertov S, et al. Aspects of using modern nanotechnologies in dentistry. Rev Amazonia Investiga. 2023;12(69):432–440. doi:10.34069/ai/2023.69.09.26.
29. Ma J. Potential Hazards of Nanostructured Dental Materials. Mater Horiz. 2023;12(5):223–245. doi:10.1007/978-981-19-8718-2_13.

30. Bezerra de Carvalho JC, França R. Nanometals and Metal Ion Pollution in Dental Environment. Micro. 2023;3(2):45–55. doi:10.3390/micro3020031.

31. Subramani K, et al. Nanobiomaterials in clinical dentistry. Res Adv Dent Biomater. 2012;8(1):156–175.

32. Kaswer A, et al. Nanofilters for Hospital Waste Disposal. Nano Biomed Eng. 2023;12(1):45–56. doi:10.26599/nbe.2023.9290017.

33. Nanomaterial waste management. J Environ Eng Sci. 2022;14(3):112–130.

34. Nanomaterial recycling: an overview. J Environ Eng Sci. 2022;14(4):132–148.

35. Holder AL, et al. Nanomaterial disposal by incineration. Environ Sci Process Impacts. 2013;15(3):356–362. doi:10.1039/C3EM00224A.

36. Gazsó A. Nanowaste: Nanomaterial-containing products at the end of their life cycle. Nanotechnol Rev. 2014;5(2):231–243.