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Review

Nanotechnology in Endodontics: A Contemporary Review

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Abstract

Nanotechnology is revolutionizing the field of endodontics by providing advanced solutions to persistent clinical challenges, particularly in root canal disinfection, material enhancement, and regenerative procedures. Conventional endodontic techniques, though effective, often fail to fully eradicate microbial biofilms due to complex root canal anatomy. Nanoparticles, with their unique physicochemical properties and nanoscale dimensions (1–100 nm), offer improved penetration, increased surface reactivity, and targeted antimicrobial action. Silver nanoparticles (AgNPs), chitosan nanoparticles, and zinc oxide nanoparticles (ZnO NPs) exhibit broad-spectrum antibacterial activity by disrupting biofilms, generating reactive oxygen species (ROS), and improving therapeutic outcomes. Nano-enhanced irrigants and medicaments, such as nano-silver solutions and modified triple antibiotic pastes, demonstrate superior antimicrobial efficacy and reduced cytotoxicity. Furthermore, nanoparticles integrated into obturation materials enhance sealing ability, biocompatibility, and mechanical properties, while nano-hydroxyapatite promotes remineralization. In regenerative endodontics, nanofibrous scaffolds and nanoparticle-based drug delivery systems facilitate stem cell proliferation and controlled growth factor release. Diagnostic applications include quantum dots and magnetic nanoparticles, improving imaging precision and treatment monitoring. Despite promising benefits, challenges such as cytotoxicity, lack of standardized protocols, and limited clinical trials remain. Continued research and interdisciplinary collaboration are essential to translate nanotechnology into routine endodontic practice.

Keywords: Nanotechnology, Nanoparticles, Endodontics, Root Canal Disinfection, Regenerative Endodontics, Nano-irrigants, Nano-materials

INTRODUCTION

Nanotechnology has emerged as a transformative domain in medical and dental sciences, significantly enhancing diagnostic and therapeutic outcomes [1]. In endodontics, the application of nanoparticles offers new avenues for improved disinfection, superior material properties, enhanced imaging, and regenerative procedures [2]. This review presents a comprehensive analysis of the current and potential uses of nanotechnology in endodontics, focusing on nanoparticle-based irrigants, medicaments, obturation materials, diagnostic tools, and regenerative techniques. The integration of nanotechnology into endodontic practice promises to revolutionize root canal treatment protocols, improving patient outcomes and procedural efficacy [3].

Endodontic therapy, a cornerstone of restorative dental procedures, aims at the elimination of microbial infection from the root canal system and the preservation of natural dentition [4]. While conventional endodontic methods rely on chemical irrigants and mechanical instrumentation to disinfect the canal space, they often fall short in fully eradicating bacterial biofilms, especially in complex anatomical regions like isthmuses, lateral canals, and apical ramifications [5]. This limitation has sparked a surge in interest in advanced technologies that can enhance the efficacy of endodontic disinfection. Nanotechnology, which involves the manipulation of materials at the nanoscale (1–100 nm), has emerged as a promising adjunct in modern endodontics due to its unique physicochemical properties [6]. The increased surface area, high reactivity, and ability to penetrate hard-to-reach spaces make nanoparticles ideal for targeted antimicrobial therapy, improved material properties, and regenerative procedures.

Nanoparticles in Root Canal Disinfection

Microbial biofilms within the root canal are the primary cause of endodontic infections, and their resistance to conventional antimicrobial agents presents a significant treatment challenge. Recent studies have explored the potential of various nanoparticles to enhance the antimicrobial efficacy of root canal disinfection protocols. Silver nanoparticles (AgNPs) are among the most extensively studied due to their potent and broad-spectrum antimicrobial activity [7,8]. AgNPs act by disrupting bacterial cell membranes, generating reactive oxygen species (ROS), and interfering with microbial DNA replication, ultimately leading to cell death. Chitosan nanoparticles, derived from natural polysaccharides, are known for their biodegradability, biocompatibility, and antimicrobial and chelating properties, making them suitable for use as adjuncts to conventional irrigants [9]. Zinc oxide nanoparticles (ZnO NPs) have also shown promise due to their photocatalytic properties and ability to generate ROS, leading to bacterial inactivation [10]. These nanoparticles are increasingly being incorporated into intracanal medicaments and sealer formulations to enhance their therapeutic properties.

Nano-Enhanced Irrigants and Medicaments

The integration of nanoparticles into root canal irrigants and medicaments has led to the development of more efficient antimicrobial formulations. Conventional irrigants such as sodium hypochlorite (NaOCl) and chlorhexidine (CHX) are limited by their inability to completely penetrate the depth of dentinal tubules and biofilms [5]. Nano-chlorhexidine and nano-silver solutions have shown enhanced penetration capabilities and increased substantivity, thereby offering prolonged antimicrobial action [11,12]. Moreover, Triple Antibiotic Paste (TAP), a widely used intracanal medicament in regenerative endodontics, has been modified with nanoparticles to improve its antimicrobial potency and reduce cytotoxic effects on host tissues [13]. These modifications enable a more sustained and targeted release of therapeutic agents, ensuring deeper and more effective disinfection.

Nanoparticles in Obturation Materials

The sealing of the root canal system following disinfection is critical to the long-term success of endodontic therapy. Nanoparticles have been integrated into sealers and obturation materials to enhance their physical and biological properties. Bioceramic-based sealers enhanced with nanoparticles exhibit superior flowability, adaptability to canal walls, and excellent sealing capabilities [14,15]. They also demonstrate intrinsic antimicrobial properties, reducing the likelihood of reinfection. Nano-hydroxyapatite, a synthetic analog of natural bone mineral, has shown to improve the bond strength of obturating materials and promote remineralization of the dentinal matrix [16]. These properties contribute to improved sealing and long-term stability of the root canal filling.

Applications in Regenerative Endodontics

Regenerative endodontics aims to restore the pulp-dentin complex through the use of biologically based procedures. Nanotechnology plays a crucial role in this field by enabling the design of advanced scaffolds and controlled drug delivery systems. Nanofibrous scaffolds made from biodegradable polymers provide a favorable environment for stem cell proliferation and differentiation, closely mimicking the natural extracellular matrix [17,18]. Additionally, nanoparticles can be used as carriers for the sustained release of growth factors such as bone morphogenetic proteins (BMPs) and vascular endothelial growth factor (VEGF), which are essential for tissue

regeneration [19]. These innovations have significantly improved the predictability and success of regenerative procedures, offering a paradigm shift in endodontic therapy.

Diagnostic Applications

Beyond therapeutic applications, nanotechnology also holds promise in the diagnostic realm of endodontics. Quantum dots and magnetic nanoparticles are being explored for their potential in enhancing imaging modalities such as cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI) [20]. These nanoparticles can improve contrast resolution and enable more precise visualization of periapical lesions and root canal anatomy. Furthermore, nanosensors capable of detecting bacterial metabolites or inflammatory biomarkers are under development. These sensors could offer real-time monitoring of infection status and treatment outcomes, thereby personalizing and optimizing patient care [21].

Challenges and Limitations

Despite the promising advantages of nanotechnology in endodontics, there are notable challenges that must be addressed before widespread clinical implementation. One major concern is the potential cytotoxicity and biocompatibility of certain nanoparticles. While many materials are deemed safe in vitro, their behavior in complex in vivo environments can vary significantly [22]. Additionally, there is a lack of standardized protocols regarding the concentration, size, and surface characteristics of nanoparticles used in endodontic materials [23]. The absence of long-term clinical studies also limits the ability to predict their efficacy and safety over time. Ethical and regulatory considerations related to the use of nanomaterials in human subjects further complicate their clinical translation [24].

Future Directions

Future research in this field should prioritize the development of safe, multifunctional nanoparticles that can simultaneously provide antimicrobial action, support tissue regeneration, and enhance material properties [25]. Efforts must be made to standardize the formulation and application protocols for nanoparticle-based products to ensure consistent clinical outcomes [26]. Furthermore, well-designed randomized controlled trials are essential to validate the benefits and safety of nanotechnology-based interventions in endodontics [27]. Continued interdisciplinary collaboration among material scientists, microbiologists, and dental clinicians will be crucial for the successful integration of nanotechnology into everyday dental practice.

Finally, Nanotechnology represents a revolutionary advancement in the field of endodontics, offering innovative solutions to some of the most persistent challenges in root canal therapy. By enabling improved disinfection, enhanced material performance, and successful regenerative procedures, nanoparticles have the potential to transform clinical outcomes and elevate the standard of care [28]. Although certain barriers to clinical application still exist, ongoing research and technological advancements are expected to address these limitations. As nanotechnology continues to evolve, its integration into endodontic practice will likely become more widespread, ultimately benefiting patients through more effective and predictable treatments [29].

CONCLUSION

Nanotechnology has emerged as a transformative innovation in endodontics, addressing longstanding challenges in root canal disinfection, sealing, and regeneration. The unique properties of nanoparticles, such as enhanced antimicrobial action, high surface reactivity, and improved material performance, hold the potential to significantly improve clinical outcomes. Applications range from nano-enhanced irrigants and obturation materials to advanced regenerative scaffolds and diagnostic tools. However, challenges like cytotoxicity, standardization of nanoparticle formulations, and limited long-term clinical data must be resolved before widespread clinical adoption. Future research should focus on developing safe, multifunctional nanomaterials and conducting robust clinical trials to establish their efficacy. With continued advancements, nanotechnology is poised to redefine the future of endodontic therapy.

REFERENCES

1. Mitra S, Revathi R, Jain N, Prasad D. Nanotechnology in Dentistry: A Review. J Oral Biol Craniofac Res. 2014;4(2):86–91.
2. Kishen A. Nanotechnology in Endodontics: Current and Potential Clinical Applications. Int Endod J. 2015;48(10):1005–13.
3. Shrestha A, Kishen A. Antibiofilm Efficacy of Photosensitizer-Functionalized Bioactive Nanoparticles on Multispecies Biofilm. J Endod. 2014;40(10):1604–10.

4. Ingle JI, Bakland LK, Baumgartner JC. Ingle's Endodontics. 7th ed. Hamilton, Ontario: BC Decker Inc; 2019.
5. Zehnder M. Root Canal Irrigants. J Endod. 2006;32(5):389–98.
6. Ahamed M, AlSalhi MS, Siddiqui MK. Nanotoxicity: Physiological Effects of Nanoparticles. Biochem Biophys Res Commun. 2010;396(3):345–9.
7. Estrela C, et al. Mechanism of Action of Sodium Hypochlorite. Braz Dent J. 2002;13(2):113–7.
8. Morones JR, et al. The Bactericidal Effect of Silver Nanoparticles. Nanotechnology. 2005;16(10):2346–53.
9. Divya K, Jisha MS. Chitosan Nanoparticles Preparation and Applications. Int J Biol Macromol. 2018;108:1489–99.
10. Raghupathi KR, et al. Size-Dependent Bacterial Growth Inhibition and Mechanism of Antibacterial Activity of Zinc Oxide Nanoparticles. Langmuir. 2011;27(7):4020–8.
11. de Almeida JF, et al. Evaluation of the Effectiveness of Nano-silver Solution in Root Canal Disinfection. J Appl Oral Sci. 2014;22(6):505–13.
12. Wu D, et al. Evaluation of the Antibacterial Efficacy of Silver Nanoparticles against Enterococcus faecalis Biofilm. Int J Nanomedicine. 2015;10:453–62.
13. Rai M, et al. Silver Nanoparticles as a New Generation of Antimicrobials. Biotechnol Adv. 2009;27(1):76–83.
14. Zhang W, et al. Assessment of a New Root Canal Sealer's Apical Sealing Ability. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107(6):e79–82.
15. Candeiro GTM, et al. Evaluation of Radiopacity, pH, Release of Calcium Ions, and Flow of a Bioceramic Root Canal Sealer. J Endod. 2012;38(6):842–5.
16. Bohner M. Resorbable Biomaterials as Bone Graft Substitutes. Mater Today. 2010;13(1–2):24–30.
17. Bottino MC, et al. Preparation and Characterization of Cell-Free and Cell-Seeded Polymeric Scaffolds for Endodontic Regeneration. J Endod. 2013;39(6):693–701.
18. Ruparel NB, et al. Direct Effect of Intracanal Medicaments on Survival of Stem Cells of the Apical Papilla. J Endod. 2012;38(10):1372–5.
19. Chen FM, et al. Toward Delivery of Multiple Growth Factors in Tissue Engineering. Biomaterials. 2010;31(24):6279–308.
20. Liu J, et al. Renal Clearable Inorganic Nanoparticles: A New Frontier of Bionanotechnology. Mater Today. 2013;16(12):477–86.
21. Li CZ, et al. Electrochemical Detection of Dental Pathogens Using a Microfluidic Sensor. Biosens Bioelectron. 2010;25(12):2632–8.
22. Oberdörster G, et al. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect. 2005;113(7):823–39.
23. Bhardwaj A, et al. Risk Assessment of Nanoparticles. Environ Toxicol Pharmacol. 2010;29(3):301–8.
24. Fadeel B, et al. Adverse Effects of Engineered Nanomaterials: Exposure, Toxicology, and Impact on Human Health. Amsterdam: Academic Press; 2012.
25. Laurenti M, Cauda V. Engineered Nanoparticles for Endodontic Therapy. Materials (Basel). 2018;11(9):1704.
26. Durán N, et al. Antibacterial Effect of Silver Nanoparticles Produced by Fungal Process on Textile Fabrics and Their Effect on Human Cells. Nanomedicine. 2007;3(1):95–101.
27. Peters OA, et al. A Micro–CT Evaluation of Root Canal Preparation Using a Novel Instrumentation Concept. Int Endod J. 2010;43(3):185–93.
28. Kishen A. Advanced Therapeutic Materials for Endodontic Disinfection. Int Endod J. 2010;43(7):547–59.
29. Shrestha A, et al. Nanoparticle-Enabled Disinfection of Dental Biofilm. J Dent Res. 2013;92(10):932–8.