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IP Indian Journal of Conservative and Endodontics

Journal homepage: https://ijce.in/

Editorial

The Power of Mighty Mini: Nanotechnology a New Era in Endodontic Care

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Keywords: Antimicrobial, Biofilm, Chitosan, Endodontics, Nanoparticles.

Received: 05-09-2025; **Accepted:** 21-09-2025; **Available Online**: 08-10-2025

Science is once again at the threshold of a revolutionary transformation, guiding humanity into a new epoch defined by nanotechnology and the application of nanoparticles. The prefix *"nano"* originates from the Greek word *"nanos,"* meaning *"dwarf,"* symbolizing the minute scale at which this field operates. In scientific terms, *nano* refers to dimensions on the order of one-billionth of a meter (10^{-9} m), a scale so small that it enables manipulation of matter at the atomic and molecular levels.[1] This unprecedented control over materials at the nanoscale has opened pathways to innovations across diverse disciplines, including medicine, electronics, energy, and dentistry, thereby reshaping the boundaries of modern science and technology.[2,3]

Furthermore, nanotechnology refers to the manipulation of matter at the scale of nanometers measured in billionths of a meter approximately equivalent to the dimension of two to three atoms. Its introduction into dentistry, especially the field of endodontics, has been innovative. By enabling modifications at the nanoscale, nanotechnology significantly enhances the physicochemical characteristics of dental materials, thereby improving their biocompatibility, functionality, and clinical acceptance. Nanoparticles have one or more external dimensions in the size range from 1 nm to 100 nm.[3,4] Nanomaterials exhibit distinctive physicochemical characteristics, including extremely small dimensions, a high surface area-to-mass ratio, and enhanced chemical reactivity, which differentiate them from their bulk equivalents.

In addition, the synthesis of nanomaterials and nanostructures represents a fundamental component of nanoscience and nanotechnology. The emergence of novel physical properties and diverse applications becomes feasible only when nanostructured materials are engineered with precise control over their size, shape, morphology, crystal structure, and chemical composition. Top-down and Bottom-up strategies are used for the synthesis of nanomaterial.[5,6]

Nanoparticles (NPs) exert their antimicrobial activity through several mechanisms, one of which is electrostatic interaction and membrane disruption. Positively charged NPs are strongly attracted to the negatively charged bacterial cell surface, resulting in their accumulation on the membrane. This interaction compromises the integrity of the cell wall, enhances membrane permeability, and facilitates further NP penetration, ultimately leading to cytoplasmic leakage. Additionally, NP binding to mesosomes disrupts vital processes such as respiration, cell division, and DNA replication.[2,6]

Another mechanism is the disruption of metal ion homeostasis, a process essential for microbial metabolism. An excess of metal-based nanoparticles (NPs) disturbs this balance, leading to irreversible cellular damage that results in growth inhibition or microbial death.[5]

A third mechanism involves the generation of reactive oxygen species (ROS), where nanoparticles (NPs) penetrate microbial membranes and trigger ROS production. The

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https://doi.org/10.18231/j.ijce.34143.1759913083

resulting oxidative stress impairs respiration, reduces ATP synthesis, and damages cellular membranes. In particular, metal oxide NPs promote ROS formation through redox cycling and the activity of pro-oxidant surface groups.[5,7]

Fourth is protein and enzyme dysfunction, where nanoparticles (NPs) catalyse oxidative modification of amino acids, resulting in the formation of protein-bound carbonyls. This process leads to protein degradation, enzyme inactivation, and loss of catalytic activity. Lastly, nanoparticles (NPs) induce genotoxicity and signal transduction impairment by interacting with nucleic acids, which disrupts DNA replication and alters cellular signaling pathways, ultimately leading to compromised microbial viability.[5,7]

Moreover, rapid advancements in nanotechnology have led to diverse biomedical applications, including drug delivery, tissue regeneration, antimicrobial therapy, gene transfection, and imaging. In dentistry, the concept of nano-dentistry refers to the use of nanomaterials and dental nanorobots for diagnosis and treatment, aimed at enhancing overall oral health. Its potential applications extend across a broad spectrum of dental care, encompassing the management of dentin hypersensitivity, biofilm removal, oral cancer diagnosis and therapy, and the development of bone replacement materials, among others.[7]

In endodontics, the advancement of nanomaterials is primarily directed toward enhancing antimicrobial activity, reinforcing the structural integrity of compromised dentin, and promoting tissue regeneration. Emerging technologies are being explored to address the persistent microbial challenge, as bacterial biofilms remain the principal cause of both primary and secondary root canal infections.[8] Traditionally, topical chemical antimicrobials combined with mechanical instrumentation have been employed to reduce microbial load before obturation with an inert filling material. However, this conventional approach, including the use of topical or systemic antibiotics, has often proven inadequate due to multiple limitations.[2,6]

Due to shortcomings in current antibiofilm strategies during root canal treatment, advanced disinfection strategies are being developed and tested. For the first time, it has been observed that dentin treated with nanoparticles resulted in significantly reduced adherence of Enterococcus faecalis.[7,8] The antibacterial efficacy of Chitosan nanoparticles (CS-NPs) and zinc oxide in disinfecting and disrupting E. faecalis (ATCC and OG1RF) biofilms was evaluated later. These nanoparticles eliminated biofilms on a concentration- and time-dependent manner and also retained their antibacterial properties after aging for 90 days.[7,9]

In addition, CS-NPs combined with various formulations of chlorhexidine have been shown to effectively eliminate E. faecalis, with promising applications in tissue regeneration using membrane barriers during periapical surgery. Bioactive glass (BAG) has also gained significant attention due to its osteoconductive properties and antibacterial activity in both orthopaedic and dental contexts. Similarly, silver compounds and nanoparticles, widely recognized for their antibacterial efficacy in biomedicine, have been investigated in dentistry for use as restorative materials, endodontic retrograde fillings, dental implants, antimicrobial and caries-preventive agents.[7,9]

Although the nanoscale dimensions of these materials provide unique physicochemical properties and promising applications in endodontics, they also pose safety concerns, as nanoparticles can circulate systemically, accumulate in vital organs, traverse the blood–brain barrier, and trigger oxidative stress, inflammation, or even carcinogenic effects, as reported with TiO_2, ZnO, and Ag nanoparticles. Despite their considerable antibacterial and regenerative potential, unresolved issues remain regarding biocompatibility, human safety, ethical considerations, cost, and limited knowledge of nanomaterial–cell interactions. Therefore, comprehensive long-term clinical studies and well-defined risk assessment strategies are crucial to ensure that their therapeutic benefits outweigh potential health risks.[3,4,6]

Thus, while nanotechnology holds immense promise for revolutionizing endodontic therapy, its successful clinical translation ultimately depends on striking a careful balance between therapeutic efficacy and biosafety through rigorous research and long-term validation.

Conflict of Interest

None.

References

1. Couvreur P. Nanoparticles in drug delivery: past, present and future. *Adv Drug Deliv Rev*. 2013;65(1):21–3. https://doi.org/10.1016/j.addr.2012.04.010.
2. Yohan D, Chithrani BD. Applications of nanoparticles in nanomedicine. *J Biomed Nanotechnol*. 2014;10(9):2371–92. https://doi.org/10.1166/jbn.2014.2015.
3. Wolfram J, Zhu M, Yang Y, Shen J, Gentile E, Paolino D, et al. Safety of nanoparticles in medicine. *Current Drug Targets*. 2015;16(14):1671–81. https://doi.org/10.2174/1389450115666140804124808.
4. Curtis A, Wilkinson C. Nanotechniques and approaches in biotechnology. *TRENDS Biotechnol*. 2001;19(3):97–101. https://doi.org/10.1016/s0167-7799(00)01536-5.
5. Venugopal J, Prabhakaran MP, Low S, Choon AT, Zhang YZ, Deepika G, Ramakrishna S. Nanotechnology for nanomedicine and delivery of drugs. *Curr Pharm Des*. 2008;14(22):2184–200. https://doi.org/10.2174/138161208785740180.
6. Costerton JW, Lewandowski Z, DeBeer D, Caldwell D, Korber D, James G. Biofilms, the customized microniche. *J Bacteriol*. 1994;176(8):2137–42. https://doi.org/10.1128/jb.176.8.2137-2142.1994.
7. Chandak PG, Chandak MG, Relan KN, Chandak M, Rathi C, Patel A. Nanoparticles in Endodontics - A Review. *J Evolution Med Dent Sci*. 2021;10(13):976–82. https://doi.org/10.14260/jemds/2021/209

8. Jain G, Shukla P, Misra P, Hans M, Rastogi S, Verma S. Investigation of the potential of nanoparticles as a new drug delivery system for endodontic treatment: An in vitro study. *J Pharm Bioall Sci*. 2024;16(Suppl 1):S921–3. https://doi.org/10.4103/jpbs.jpbs_1093_23.
9. Moraes G, Zambom C, Siqueira WL. Nanoparticles in Dentistry: A Comprehensive Review. *Pharmaceuticals*. 2021;14(8):752. https://doi.org/10.3390/ph14080752.

Cite this article: Jain G. The Power of Mighty Mini: Nanotechnology a New Era in Endodontic Care. *IP Indian J Conserv Endod*. 2025;10(3):135-137.