

Review Article

An overview of nanobots in endodontics

Ainaa Abdulmoeen Alsharif^{1*}, Mohammad Yahya Assiri², Faris Tariq Alsurayyi³,
Areej Ayedh Alsanad⁴, Abrar Abdulrahman Alhamadi⁵, Nwaf Mohammad Alqahtani⁴

¹North Jeddah Specialized Dental Center, King Abdullah Medical Complex, Jeddah, Saudi Arabia

²Department of Dentistry, Almasif Primary Healthcare, Ministry of Health, Riyadh, Saudi Arabia

³Department of Dentistry, Zayan Dental Clinic, Riyadh, Saudi Arabia

⁴Department of Dentistry, King Khalid University, Abha, Saudi Arabia

⁵Department of Dentistry, Alwaha Healthcare Center, Ministry of Health, Jeddah, Saudi Arabia

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*Correspondence:

Dr. Ainaa Abdulmoeen Alsharif,

E-mail: Dr.Aynaa_alsharif@hotmail.com

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ABSTRACT

Nanorobots are emerging as a transformative technology in endodontics, with the potential to enhance the precision, efficacy, and overall success of root canal treatments. These microscopic devices are capable of navigating the intricate architecture of root canals, identifying and eliminating microbial pathogens, and delivering targeted therapeutic agents with high specificity. By accessing areas that conventional endodontic instruments cannot reach, nanorobots may facilitate more thorough decontamination and reduce the risk of reinfection. Current research focuses on optimizing their biocompatibility, structural integrity, and controllability to ensure both safety and effectiveness in clinical applications. However, several challenges must be addressed before nanorobots can be integrated into routine dental practice. These include high production costs, technical limitations, and the necessity of regulatory approval to ensure their clinical viability. To overcome these barriers, researchers are exploring advanced strategies such as magnetic field navigation, computer-assisted control, and the development of biodegradable nanobots capable of self-dissolution upon task completion. With continued technological advancements, nanorobots have the potential to revolutionize endodontic treatment by offering minimally invasive, highly targeted interventions that enhance procedural success rates and patient recovery. Their autonomous functionality may also reduce reliance on conventional endodontic instruments, thereby reshaping current treatment methodologies. As the field progresses, interdisciplinary collaboration among scientists, engineers, and dental professionals remains essential to addressing existing limitations and facilitating the transition of nanorobots from experimental models to standardized clinical use. This review examines recent developments in nanorobotics, evaluates their advantages and limitations, and discusses their prospective role in the future of root canal therapy.

Keywords: Nanobots, Endodontics, Nanotechnology, Dental, Dental health, Dentistry

INTRODUCTION

Endodontics is a specialized field of dentistry focused on diagnosing, treating, and preventing diseases of the dental pulp and surrounding tissues. Root canal therapy is typically performed when a tooth suffers irreversible damage accompanied by infection.¹ The primary goal of endodontics is to preserve natural teeth, avoiding

extractions that may require complex and costly procedures. Successful endodontic treatment not only saves the affected tooth but also contributes to overall oral health.²

Advancements in technology have significantly enhanced surgical and dental procedures, improving efficiency, precision, and patient outcomes. One of the most

promising developments in recent years is nanotechnology, which involves manipulating matter at the molecular or atomic scale, typically under 100 nanometers.³ In medicine, nanotechnology is already revolutionizing diagnostics, drug delivery, and various surgical techniques due to its unparalleled precision.⁴ In dentistry, its potential is particularly evident in dental pulp therapy, where nanotechnology addresses long-standing challenges of conventional treatments.

Among the most groundbreaking applications is the development of nanorobots, microscopic machines capable of performing highly precise tasks at the cellular level. These nanobots could be designed to eliminate infections, promote tissue regeneration or deliver targeted medications directly to damaged pulp while sparing surrounding healthy tissue.⁵ Their ability to navigate the intricate root canal system could improve cleaning effectiveness, reduce human error, and optimize treatment outcomes.^{6,7}

Current endodontic methods, though effective, are limited by anatomical complexity and manual precision. Nanorobots offer a transformative alternative by automating tedious processes and enhancing accuracy.⁸ While still in experimental stages, ongoing research and clinical trials indicate promising advancements. As nanotechnology progresses, its integration into dentistry is expected to refine treatment approaches, making procedures less invasive and more efficient.⁹

However, several critical questions remain regarding the applications, limitations, and ethical implications of nanorobots in everyday dental practice. Continued interdisciplinary research involving scientists, engineers, and dental professionals is essential to overcoming these challenges.¹⁰

This article explores the concept of nanorobots in endodontics, their potential benefits, existing barriers, and the future trajectory of this technology in revolutionizing root canal treatment.

LITERATURE SEARCH

This narrative review is based on a comprehensive literature search conducted on March 6, 2025, in the Medline, Scopus, and Cochrane databases. Utilizing medical subject headings (MeSH) and relevant keywords, the search aimed to provide an overview of nanobots in endodontics. To ensure thoroughness, a manual search was conducted using Google Scholar, and the reference lists of identified papers were reviewed to locate additional relevant studies. The review focused on articles addressing the use of nanobots in endodontics, their promising role in dentistry, and what are these advantages, disadvantages and limitations. No restrictions were applied regarding publication date, language, participant age, or type of publication, ensuring a broad and inclusive exploration of the available literature.

DISCUSSION

Regarding the development of new technologies, one of the most intriguing advancements is the application of nanoscale specialized machinery, known as nanobots, which could significantly transform endodontic therapy.¹¹ This section explores nanobots in endodontics, their mechanisms, advantages, challenges, and future potential. Nanobots are microscopic robots, typically measured in nanometers (one billionth of a meter), designed to perform highly specialized molecular or cellular functions.¹² Emerging from the field of nanotechnology, which involves macromolecular engineering at the atomic and molecular levels, nanobots are designed to enhance biological functions by delivering targeted treatments or assisting in cellular repair. These devices can interact with tissues, eliminate pathogens, and deliver therapeutic agents with precision.¹³ Nanotechnology has achieved remarkable progress, particularly in healthcare, with applications in drug delivery, surgery, and diagnostics. The logical extension of these developments is the integration of nanobots into endodontics, where they can operate on a microscopic scale with unparalleled accuracy.¹⁴

Nanobots utilize mechanical, chemical, and electrical processes to perform their functions within biological systems. Many medical nanobots are externally powered using magnetic fields or ultrasound, allowing precise tracking and control. Others respond to internal biological cues, such as pH levels or specific chemical markers, to autonomously execute their programmed tasks.¹⁵ In oncology, for example, nanobots can identify cancer cells based on specific surface indicators and administer targeted treatments. In endodontics, these devices could navigate the complex root canal system, deliver medications, clean infected sites, and even promote tissue regeneration.¹⁶

Endodontics focuses on diagnosing and treating diseases affecting the dental pulp and surrounding tissues. Root canal therapy is a common procedure that removes infected or necrotic tissue, disinfected the canal, and seals it with biocompatible material.¹⁷ However, due to the complexity of the root canal system, complete sterilization remains challenging, and reinfections persist despite advancements in conventional techniques. Nanobots offer a promising solution by improving precision and effectiveness.¹⁸ Their ability to navigate intricate anatomical structures allows them to thoroughly remove debris, bacteria, and infected tissue from areas inaccessible to conventional tools. This capability enhances debridement efficiency and improves treatment outcomes. Furthermore, nanobots can facilitate the targeted delivery of antibiotics or therapeutic agents deep within the root canal system, ensuring optimal concentration and distribution. This precise approach significantly enhances sterilization and reduces reinfection risks.¹⁹ Another critical application is regenerative endodontics, where nanobots could aid tissue

regeneration by delivering growth factors or stimulating cellular repair. This could accelerate the healing of pulp and periapical tissues, leading to better long-term outcomes.²⁰

Nanobots offer several advantages in endodontic procedures. Their precision enables effective cleaning and disinfection of root canals, surpassing the limitations of conventional techniques.¹⁹ They minimize human error by standardizing procedures and ensuring more predictable outcomes.²¹ Their capacity for targeted drug delivery improves the effectiveness of sterilization, reducing the risk of reinfection and promoting faster healing.²² Additionally, by minimizing damage to surrounding healthy tissues, nanobots contribute to less invasive procedures, reduced post-operative discomfort, and quicker recovery times.

Despite their potential, nanobots face several challenges. The technology is still in its early stages, with limitations in size, functionality, and control, making current models insufficient for complex medical applications.²³ Another major concern is biocompatibility and safety, as the introduction of foreign nanomaterials into the human body raises questions about toxicity and potential immune responses.²⁴ Ethical and regulatory barriers must also be addressed. The use of nanotechnology in medicine brings concerns regarding patient consent, data security, and potential misuse. Additionally, regulatory frameworks must establish clear guidelines for clinical applications.²⁵ Economic feasibility poses another challenge, as the development and deployment of nanobot technology remain costly, potentially limiting widespread adoption in dental practice.²⁶ Ongoing research is focused on refining nanobot design, improving efficiency, and overcoming these challenges. Advances in targeted drug delivery and tissue regeneration have yielded promising results in experimental trials, indicating potential future applications in clinical settings.²⁷ Collaboration among researchers, engineers, and dental professionals will be crucial in overcoming technological and ethical obstacles to integrate nanobots into endodontics.

With rapid technological advancements, nanobots are expected to become integral to endodontic procedures, offering increased precision and efficiency while minimizing complications.²⁸ Future innovations could lead to even more advanced nanobots capable of real-time treatment monitoring, enhanced sterilization techniques, and integration with emerging technologies such as artificial intelligence and 3D printing.⁴ The convergence of these innovations could revolutionize endodontic treatment, making procedures more precise, efficient, and patient-friendly.²⁹

CONCLUSION

Although still in its developmental stages, nanobot technology holds great promise for the future of endodontics. Current research highlights its potential in

targeted drug delivery, improved root canal sterilization, and enhanced tissue regeneration. While clinical applications remain limited, advancements in nanorobotics and materials science suggest a future where nanobots optimize treatment precision, reduce procedural failures, and improve patient comfort. However, addressing concerns related to biocompatibility, cost, and regulatory approval is essential for their successful implementation. With continued research and interdisciplinary collaboration, nanobots could redefine endodontic practice, providing more effective, minimally invasive, and technologically advanced solutions for preserving natural teeth.

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