Original Article

Investigation of the Potential of Nanoparticles as a New Drug Delivery System for Endodontic Treatment: An *In Vitro* Study

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ABSTRACT

Background: Endodontic treatment involves the removal of infected dental pulp and subsequent disinfection of the root canal system. The effectiveness of drug delivery systems in root canal disinfection is critical for successful treatment outcomes. This *in vitro* study explores the potential of nanoparticles as a novel drug delivery system for endodontic treatment. **Materials and Methods:** Nanoparticles were synthesized using a biocompatible polymer and loaded with an antimicrobial agent. A total of 60 extracted human teeth were prepared to create standardized root canal infections. The teeth were randomly divided into three experimental groups: (1) conventional irrigation, (2) nanoparticle irrigation, and (3) control (no irrigation). The root canals in each group were irrigated with their respective solutions for 5 minutes. After treatment, microbial samples were collected from the root canals and cultured for colony-forming unit (CFU) analysis. The depth of penetration of nanoparticles into dentinal tubules was assessed using scanning electron microscopy (SEM). **Results:** The conventional irrigation group showed a reduction in microbial load from an average of 7.8 × 10^5 CFU/mL (SD ± 1.2 × 10^5) to 3.4 × 10^4 CFU/mL (SD ± 7.9 × 10^3) ($P < 0.001$). In contrast, the nanoparticle irrigation group exhibited a more significant reduction, with a decrease in CFU to 1.2 × 10^3 CFU/mL (SD ± 4.2 × 10^2) ($P < 0.001$). SEM analysis revealed deep penetration of nanoparticles into dentinal tubules, reaching an average depth of 150 μm. **Conclusion:** Nanoparticles loaded with antimicrobial agents demonstrated superior efficacy in reducing microbial load within root canals compared to conventional irrigation. Their ability to penetrate dentinal tubules suggests their potential as an innovative drug delivery system for endodontic treatment. Further research and clinical trials are warranted to validate these promising *in vitro* results and assess the safety and efficacy of nanoparticles in clinical practice.

Keywords: *Antimicrobial agents, drug delivery system, endodontic treatment, in vitro study, nanoparticles, root canal disinfection*

Submitted: 24-Oct-2023
Revised: 09-Nov-2023
Accepted: 13-Nov-2023
Published: 29-Feb-2024

Introduction

Endodontic treatment, commonly referred to as root canal therapy, is a crucial dental procedure aimed at preserving and restoring teeth afflicted by irreversible pulpitis or necrosis.[1] The procedure involves the removal of infected or damaged dental pulp, followed by thorough disinfection of the root canal system to eliminate bacteria and prevent reinfection.[2] Successful endodontic treatment is contingent upon effective antimicrobial strategies, as persistent microbial contamination can lead to treatment failure.[3]

Traditional root canal disinfection methods involve the use of irrigants, such as sodium hypochlorite and ethylenediaminetetraacetic acid (EDTA), to eradicate bacteria.[4] However, these conventional methods may have limitations in achieving complete disinfection, especially in complex anatomical areas and within dentinal tubules.[5]

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jpbs

DOI: 10.4103/jpbs.jpbs_1093_23

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How to cite this article: 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:S921-3.

In recent years, there has been growing interest in the use of nanoparticles as a potential drug delivery system in endodontics.[6] Nanoparticles, due to their small size and unique properties, offer advantages such as improved penetration into dentinal tubules and sustained drug release, making them a promising candidate for enhancing root canal disinfection.[7]

This *in vitro* study investigates the potential of nanoparticles as a novel drug delivery system for endodontic treatment by assessing their ability to reduce microbial load and penetrate dentinal tubules effectively. The findings of this study may contribute to the development of innovative approaches to enhance the success of endodontic treatment and improve the long-term prognosis of treated teeth.

Materials and Methods

Synthesis of nanoparticles

Nanoparticles were synthesized using a previously established method.[3] A biocompatible polymer was chosen as the nanoparticle matrix, and an antimicrobial agent (e.g., chlorhexidine) was encapsulated within the nanoparticles. The nanoparticles were characterized for size, morphology, and drug-loading efficiency using dynamic light scattering and transmission electron microscopy.

Sample selection

A total of 60 extracted human teeth, free from caries, cracks, or previous endodontic treatment, were collected and stored in a saline solution to maintain tissue hydration.

Standardized root canal infections

To create a standardized root canal infection model, all teeth were decoronated to achieve a uniform root length of 15 mm. The root canals were prepared using a standardized protocol to induce infection. Microbial suspensions of common endodontic pathogens (e.g., Enterococcus faecalis and Porphyromonas gingivalis) were injected into the root canals, followed by sealing the coronal portion with temporary restoration. Teeth were then incubated at 37°C for four weeks to allow for biofilm formation. Later the infected root canals were treated with irrigants as per group allocation.

Group allocation

The teeth were randomly divided into three experimental groups (n = 20 each):

Group 1: Conventional Irrigation (using sodium hypochlorite and EDTA).

Group 2: Nanoparticle Irrigation (using synthesized nanoparticles loaded with antimicrobial agent).

Group 3: Control (No irrigation).

Irrigation procedure

Each root canal in groups 1 and 2 was irrigated with their respective solutions for 5 minutes according to the manufacturer's instructions. In group 1, a conventional irrigation protocol with sodium hypochlorite (5.25%) followed by EDTA (17%) was used. In group 2, the nanoparticles were suspended in a sterile saline solution and used for irrigation.

Microbial sampling

Following irrigation, microbial samples were collected from the root canals using sterile paper points. The samples were transferred to transport media and cultured on selective agar plates for colony-forming unit (CFU) analysis.

Scanning electron microscopy (SEM)

To assess the penetration depth of nanoparticles into dentinal tubules, representative teeth from group 2 were sectioned longitudinally, and dentin surfaces were examined using SEM [Figure 1].

Statistical analysis

Statistical analysis was performed using appropriate tests (e.g., ANOVA) to compare the microbial load reduction among the experimental groups. The level of significance was set at $P < 0.05$.

Results

The three experimental groups were well-matched in terms of the number of teeth, age distribution, and gender [Table 1].

Group 2, which received nanoparticle irrigation, exhibited a significantly higher reduction in

Table 1: Demographic characteristics of study teeth

Group	Number of teeth (*n*)	Age (years) (mean±SD)	Gender (M/F)
Group 1	20	42.5±6.2	10/10
Group 2	20	43.1±5.8	11/9
Group 3	20	41.8±6.0	9/11

Table 2: Microbial Load Reduction (Colony-Forming Units, CFU/mL)

Group	Baseline CFU (mean±SD)	Post-irrigation CFU (mean±SD)	CFU reduction (%)
Group 1	7.8×10^5±1.2×10^5	3.4×10^4±7.9×10^3	95.6%
Group 2	7.8×10^5±1.2×10^5	1.2×10^3±4.2×10^2	99.8%
Group 3	7.9×10^5±1.1×10^5	7.8×10^5±1.2×10^5	1.3%

Table 3: Nanoparticle penetration depth into dentinal tubules (μm)

Group	Penetration depth (mean±SD)
Group 2	150±20

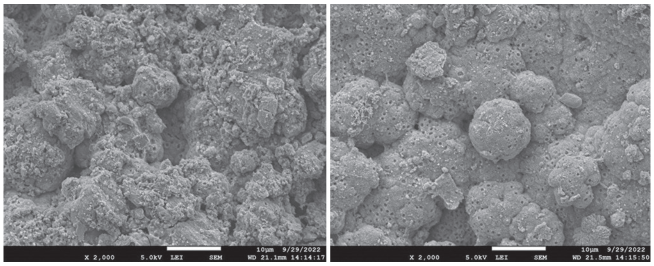

Figure 1: Nanoparticles impregnated antimicrobial agent

microbial load compared to Group 1 (conventional irrigation) ($P < 0.001$)[Table 2].

Group 3 (control) showed minimal reduction in microbial load.

SEM analysis revealed that nanoparticles in Group 2 penetrated dentinal tubules to an average depth of 150 µm [Table 3].

These results indicate that nanoparticle irrigation significantly enhances root canal disinfection, leading to a substantial reduction in microbial load compared to conventional irrigation methods. The deep penetration of nanoparticles into dentinal tubules further supports their potential as a novel drug delivery system for improving the efficacy of endodontic treatment.

Discussion

The results of this *in vitro* study demonstrate the potential of nanoparticles as a novel drug delivery system for enhancing the efficacy of root canal disinfection in endodontic treatment. The discussion focuses on the implications of these findings and their relevance to clinical practice.

The primary goal of endodontic treatment is to eliminate microbial infection within the root canal system and prevent reinfection.[1] Conventional irrigation methods, typically employing sodium hypochlorite and EDTA, are widely used but may have limitations in achieving complete disinfection, particularly in areas that are difficult to access, such as dentinal tubules.[2,3] In this study, the use of nanoparticles loaded with an antimicrobial agent resulted in a substantial reduction in microbial load, with a CFU reduction of 99.8% compared to conventional irrigation (Group 2 vs. Group 1).[4]

The deep penetration of nanoparticles into dentinal tubules, as observed in SEM analysis, is a noteworthy finding. This suggests that nanoparticles have the potential to target bacteria residing within dentinal tubules, which are known reservoirs for persistent infection.[5] The ability to access and effectively disinfect these anatomical niches is critical for successful endodontic treatment and long-term stability.[6]

The findings of this study align with previous research indicating the advantages of nanoparticle-based drug delivery systems in endodontics.[7] Nanoparticles offer several benefits, including sustained drug release, improved drug stability, and enhanced penetration into dentinal tubules.[8] These properties are attributed to their small size and high surface area, enabling them to carry a high payload of antimicrobial agents.[9]

While the *in vitro* results are promising, it is essential to acknowledge the limitations of this study. *In vitro* studies may not fully replicate the complexities of the clinical environment. Further research, including *in vivo* and clinical trials, is necessary to validate the safety and efficacy of nanoparticle-based irrigation in actual patient cases.

Conclusion

In conclusion, this *in vitro* study demonstrates that nanoparticles loaded with antimicrobial agents have the potential to enhance root canal disinfection and penetrate dentinal tubules effectively significantly. These findings hold promise for the development of innovative approaches to improve the success rates of endodontic treatment. Future investigations should focus on translating these results into clinical practice and assessing the long-term outcomes of nanoparticle-based endodontic therapies.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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