ECP 2025 Conference

The 4th International Electronic Conference on Processes

20–22 October 2025 | Online

MDPI

Sustainable Design and Engineering of Bio-Based Nanoparticles for Targeted Periodontal Therapy: From Green Synthesis to Scalable Production

Grigorios Loukas, DDS, MSc Nanomedicine

National and Kapodistrian University of Athens, Privet Dental Practice

INTRODUCTION & AIM

Background:

Periodontitis is a chronic, host-mediated inflammatory disease driven by oral microbiome dysbiosis, leading to progressive connective-tissue and bone loss. Conventional therapy—scaling and root planning (SRP) with or without antimicrobials—often fails to eradicate biofilm reservoirs in deep pockets. Systemic antibiotics increase resistance and ecological burden, while current local drug-delivery systems suffer from poor retention and wash-out. Sustainable, bio-based nanotechnology offers a new direction for precision, long-lasting, and environmentally responsible periodontal care.

Conceptual Framework:

- Green chemistry replaces toxic reducers (e.g., $NaBH_4$) with plant polyphenols and chitosan from crustacean waste.
- Gold nanoparticles (AuNPs) exhibit plasmonic activity (≈808 nm) enabling mild photothermal/photodynamic activation without antibiotics. Mucoadhesive hydrogels ensure site-specific retention and controlled release within the subgingival pocket.
- Combines antimicrobial, anti-inflammatory, and pro-regenerative mechanisms with circular-economy principles.

Aim of the Study:

To propose the development and validate the NANOPERIO-STAR Green Gold Nanoparticles —a biogenic, photothermally activable nanoplatform designed to:

- Disrupt mature polymicrobial biofilms physically rather than chemically;
- Modulate local inflammation (↓ IL-1β, TNF-α, MMP-8/9);
- Promote fibroblast and osteoblastic regeneration;
- Be produced via eco-efficient, reproducible, green-synthesis routes compliant with ISO 14040 life-cycle principles.

Figure 1. Schematic representation of periodontal therapy using green-synthesized gold nanostar nanoparticles activated by near-infrared (NIR) light (~808 nm). Illustartion created by the Author

METHOD

This study follows a **theoretical** and **literature-based research design**.

- A comprehensive **systematic review** and synthesis of recent peer-reviewed studies (2020–2025) was performed, covering topics in periodontitis etiopathogenesis, current therapeutic strategies, and nanomedicine-based interventions. Scientific databases (PubMed, Scopus, ScienceDirect) were searched using keywords such as periodontal therapy, biofilm resistance, nanomedicine, green synthesis, and gold nanoparticles.
- The analysis compared the biological and clinical limitations of existing periodontal treatments—including mechanical, pharmacological, and regenerative approaches—with the requirements for optimal therapeutic outcomes (biofilm eradication, host modulation, tissue regeneration).
- Findings from this integrative review were then aligned with nanoparticle design principles (composition, morphology, surface chemistry, biocompatibility, and sustainability) to **formulate a conceptual design proposal** for a green-engineered nanoplatform, named NANOPERIO-STAR.

RESULTS & DISCUSSION

Green Synthesis Insights:
The literature synthesis highlighted that conventional periodontal treatments, although effective short-term, fail to eradicate deep dysbiotic biofilms, control inflammation, and ensure long-term tissue stability. At the same time, classical nanoparticle synthesis methods rely on toxic reductants and energy-intensive processes. Recent studies on green synthesis using plant polyphenols, flavonoids, and biopolymers such as chitosan show that eco-friendly nanoparticles can achieve biocompatibility, stability, and therapeutic efficiency while minimizing chemical waste and aligning with circular-economy principles.

NANOPERIO-STAR Nanoplatform:
In response to these findings, the NANOPERIO-STAR system is proposed as a biogenic, multifunctional nanoplatform integrating green gold nanostars (AuNS) within a mucoadhesive in-situ forming hydrogel for localized, antibiotic-free treatment.

Structural & Functional Elements:
Core: Gold nanostar (80–120 nm; PDI ≤ 0.2) synthesized via green-tea polyphenols; LSPR ≈ 808 nm compatible with dental diode lasers.
Shell: Low-molecular-weight chitosan (from crustacean waste) providing mucoadhesion and mild cationic charge (+10 to +20 mV).
Functionalization: RGD peptides target inflamed epithelium; α-lipoic acid or resveratrol act as antioxidant and anti-MMP agents.
Carrier: Thermo-responsive chitosan/β-glycerophosphate hydrogel, gelling in situ within 2–3 min at 37 °C for prolonged retention.
Activation: 808 nm NIR laser, inducing controlled photothermal biofilm disruption (~43–45 °C) without tissue damage.

Therapeutic Performance
✓ Biofilm eradication: NIR-triggered thermal and oxidative disruption of P. gingivalis and multispecies biofilms.
✓ Host modulation: Suppression of IL-1β, TNF-α, and MMP-8/9 through antioxidant and polyphenolic surface activity.
✓ Regenerative potential: Mild heat and antioxidant synergy enhance fibroblast proliferation and osteogenic differentiation.
✓ Retention and precision: Mucoadhesive hydrogel ensures stable localization in deep or complex pockets.
✓ Sustainability: Entirely green process using renewable feedstocks, aqueous chemistry, and waste valorization.

Discussion
The NANOPERIO-STAR system embodies a translational model that bridges green nanotechnology and clinical periodontology. It satisfies the core therapeutic requirements of periodontal care—biofilm control, host-response modulation, and tissue regeneration—while embedding environmental responsibility throughout its design. This integrative strategy establishes a foundation for next-generation sustainable nanotherapies, capable of achieving both clinical efficacy and ecological safety.

CONCLUSION

The proposed NANOPERIO-STAR nanoplatform integrates green chemistry, photothermal precision, and clinical functionality into a single sustainable system. It effectively meets the biological demands of periodontal therapy—biofilm elimination, inflammation control, and regeneration. This concept demonstrates a pathway toward eco-responsible, next-generation nanotherapies in oral medicine.

SELECTED REFERENCES

Abdulkareem, A. A., Al-Taweel, F. B., Al-Sharqi, A. J. B., Gul, S. S., Shab, A., & Chapple, I. L. C. (2023). Current concepts in the pathogenesis of periodontitis: From symbiosis to dysbiosis. Journal of Oral Microbiology, 15(1), 2197779.

Haque, M. M., Yerex, K., Kelekis-Cholakis, A., & Duan, K. (2022). Advances in novel therapeutic approaches for periodontal diseases. BMC Oral Health, 22, 492.

D'Amico, E., Aceto, G. M., Petrini, M., Cinquini, C., D'Ercole, S., Iezzi, G., & Pierfelice, T. V. (2025). How will nanomedicine revolutionize future dentistry and periodontal therapy? International Journal of Molecular Sciences, 26(2), 592.

Deka, K., Nongbet, R. D., Das, K., Saikia, P., Kaur, S., Talukder, A., & Thakuria, B. (2025). Understanding the mechanism underlying the green synthesis of metallic nanoparticles using plant extract(s) with special reference to silver, gold, copper and zinc oxide nanoparticles. Hybrid Advances, 9, 100399.

Jongrungsomran, S., Thongthai, P., & Chaijareenont, P. (2024). The integration of gold nanoparticles into dental materials: A review of modified AuNPs in dentistry and their cellular effects. Bioengineering, 15(10), 291.