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Evaluating the Effect of Metal Nanoparticles in the Treatment of Peri-implantitis: A Systematic Review and Meta-analysis

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ABSTRACT

Background and aim: Plaque-related pathological conditions such as peri-implantitis (PI) affect the tissues surrounding dental implants and affect the survival of implants. Hence, treatment of PI is of great importance, but bacterial resistance has been observed with antibiotics. Hence, the use of nanoparticles has been proposed. The present study aimed to evaluate the effect of metal nanoparticles (silver nanoparticles) in the treatment of peri-implantitis.

Material and methods: The international databases PubMed, EMBASE, and Web of Science were searched using keywords aligned with the study objective up to July 2025. Two blinded, independent authors reviewed all articles. STATA/MP. v17 (College Station, Texas, USA) was used to perform the analyses.

Results: In the present study, fifteen in vitro studies were included. Antibacterial activity of AgNPs in dental implants was 60% (ES: 0.60; 95% CI, 0.54, 0.67). The effectiveness of AgNPs for the treatment of peri-implantitis was 73% (ES: 0.73; 95% CI, 0.66, 0.81).

Conclusions: The present study showed acceptable effectiveness of silver nanoparticles' antibacterial activity and reduction of inflammatory factors in the treatment of PI.

1. Introduction

Dental implants have been a popular alternative to missing teeth for decades. Studies have shown that biological complications shorten the lifespan of implants. Clinical studies comparing the long-term survival rates of implants placed in augmented bone versus those in natural bone have yielded conflicting results.[1] While some studies have reported comparable results in terms of marginal bone loss and implant survival rates, other studies have reported less than ideal results when placing implants in reinforced sites.[2, 3] Based on available evidence, periodontal inflammatory disease (PID) can occur during implant treatment. Various studies have shown that peri-implantitis (PI) has a different prevalence in different populations. Several studies have also shown a strong correlation between poor oral hygiene and PI.[4, 5] Biofilms are the primary cause of PIDs, characterized by the development of inflammatory conditions and tissue breakdown. The progression of PI leads to bone loss. However, studies have shown that the microbial profile of PI and the microbiome found in periodontitis lesions are not identical.[6] Studies have shown that although surgical outcomes after PI treatment help prevent further bone resorption and implant failure, they are still unpredictable in reducing inflammation. Evidence suggests that salvage care and implant removal are necessary in cases of further PI collapse.[7] Additionally, the issue of disinfecting the rough and threaded surfaces of exposed implants in PI is challenging and requires the use of more complex treatment techniques.[8] Research suggests that nanoparticles (NPs) may be a useful approach to addressing some of the challenges associated with dental implants. Their physical properties and sterilization could increase the survival rate of implants.[9] Metal NPs, including copper (Cu), zinc (Zn), titanium oxide (TiO2), silver (Ag), and gold (Au) NPs, can inhibit a variety of bacterial strains and treat oral health problems. Therefore, they are often used in nanoformulations to combine drug active ingredients with NPs, creating a synergistic effect.[10, 11] Studies have shown that chitosan, metal NPs, and hybrid coatings with antibiotic agents can be used to prevent PI due to their antibacterial properties. Despite the promising results of these studies, further research is needed to evaluate their clinical behavior in humans before

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they can be widely marketed.[12] Potential toxicity and slow metal accumulation are also major disadvantages of these approaches. In dental implant therapy, titanium is currently considered the most suitable biomaterial for connecting the implant abutment to the abutment.[13-15] The large surface area and high charge density of NPs enable them to interact with the negatively charged surface of bacterial cells, thereby enhancing their antibacterial activity. Metal NPs help regenerate demineralized dental tissues by enhancing biomineralization.[16] Effective management of biological complications that can compromise the long-term effectiveness of bone-integrated implant reconstructions can be challenging due to the widespread distribution of bone resorption.[17] Titanium-containing silver NPs can increase bone mineral density, bone growth, and trabecular pattern without damaging the tissues surrounding dental implants.[18] Nowadays, it is essential to treat PID with the latest advances in treatment and prevention. Therefore, metal NPs such as Cu, Zn, TiO2, Ag, and Au have been proposed for the treatment of PID. For the treatment of PI, these NPs can serve as a promising alternative to antibiotics due to their antibacterial properties. Several studies have been conducted to reduce toxicity and increase the efficacy of these metal NPs in the treatment of PID. However, a consensus of findings could provide stronger evidence; hence, the present study aimed to evaluate the effect of AgNPs in the treatment of PI.

2. Material and methods

Search strategy and selection criteria

The present study was conducted in accordance with the PRISMA 2020 checklist[19] by conducting a targeted search of the PubMed, EMBASE, and Web of Science databases up to July 2025 using relevant keywords. References of reviews and related articles were reviewed to identify additional relevant articles. Only articles published in English were considered. After conducting separate literature searches, two blinded and independent authors reviewed the titles, abstracts, and full texts of the studies.

The following Mesh terms were used to retrieve literature:

((((((((((((((((((("Dental Implants"[Mesh] OR "Dental Implantation"[Mesh]) AND "Periodontal Diseases"[Mesh]) OR ("Periodontal Diseases/classification"[Mesh] OR "Periodontal Diseases/complications"[Mesh] OR "Periodontal Diseases/diagnosis"[Mesh] OR "Periodontal Diseases/drug therapy"[Mesh] OR "Periodontal Diseases/etiology"[Mesh] OR "Periodontal Diseases/prevention and control"[Mesh] OR "Periodontal Diseases/surgery"[Mesh] OR "Periodontal Diseases/therapy"[Mesh])) OR "Peri-Implantitis"[Mesh]) OR ("Peri-Implantitis/classification"[Mesh] OR "Peri-Implantitis/complications"[Mesh] OR "Peri-Implantitis/diagnosis"[Mesh] OR "Peri-Implantitis/drug therapy"[Mesh] OR "Peri-Implantitis/etiology"[Mesh] OR "Peri-Implantitis/microbiology"[Mesh] OR "Peri-Implantitis/prevention and control"[Mesh] OR "Peri-Implantitis/surgery"[Mesh] OR "Peri-Implantitis/therapy"[Mesh])) OR "Mucositis"[Mesh]) AND "Nanoparticles"[Mesh]) OR "Metal Nanoparticles"[Mesh]) OR ("Metal Nanoparticles/administration and dosage"[Mesh] OR "Metal Nanoparticles/adverse effects"[Mesh] OR "Metal Nanoparticles/classification"[Mesh] OR "Metal Nanoparticles/microbiology"[Mesh] OR "Metal Nanoparticles/statistics and numerical data"[Mesh] OR "Metal Nanoparticles/therapeutic use"[Mesh] OR "Metal Nanoparticles/toxicity"[Mesh])) OR "Magnetic Iron Oxide Nanoparticles"[Mesh]) OR "Gold"[Mesh]) OR "Silver"[Mesh]) OR "Iron"[Mesh]) OR "Copper"[Mesh]) OR "Zinc"[Mesh]) OR "Aluminum"[Mesh]) OR "titanium dioxide" [Supplementary Concept]) AND ("Bacteria"[Mesh] OR "Microbiology"[Mesh] OR "microbiology" [Subheading])) AND "Anti-Bacterial Agents"[Mesh]) AND "Contraceptive Effectiveness"[Mesh].

Studies were included if they met the PICO strategy criteria. Population (P): Patients with implants, Intervention (I): metal nanoparticles, Comparison (C): not defined; Outcome (O): treatment outcome. Exclusion criteria include: reviews, case report studies, and literature studies; studies with unavailable or incomplete data; articles written in a language other than English.

Data extraction

Two investigators independently and blindly extracted data from each selected study using a standard "primary and secondary data extraction" form; a third reviewer resolved any disagreements between investigators. Data related to study characteristics, including the name of the first author, year of publication, sample size, methodology, and results, were selected as demographic and clinical data. The original data were then entered into the meta-analysis after extraction.

Statistical analysis

Statistical heterogeneity among studies was evaluated with the use of the I^2 statistic and Q test p-value < 0.05: No heterogeneity: 0.0% < I^2 < 24.9%; low heterogeneity: 25.0% < I^2 < 49.9%; Moderate heterogeneity: 50.0% < I^2 < 74.9%; High heterogeneity: 75.0% < I^2 < 100%. STATA/MP.v17 (College Station, Texas, USA) was used to perform the analyses. The effect size, as determined by the random effect model and the Restricted Maximum Likelihood (REML) method, was used to assess efficacy.

3. Results

Literature search

After a thorough keyword search in international databases, a significant number of articles were found, totaling 227 articles, as shown in Figure 1 . After reviewing the titles, 89 of these articles were excluded based on duplication and inconsistency with the inclusion and exclusion criteria; the abstracts of 138 articles were reviewed and studies that did not meet the study selection criteria were excluded at this stage (n=106), and two blind and independent authors reviewed the full text of 32 articles. Finally, after removing irrelevant articles, 15 articles were included in the study (Fig. 1).

Study characteristics

Fifteen in vitro studies assess the effect of Ag NPs in the treatment of peri-implantitis. Table 1 shows a summary of the study data.

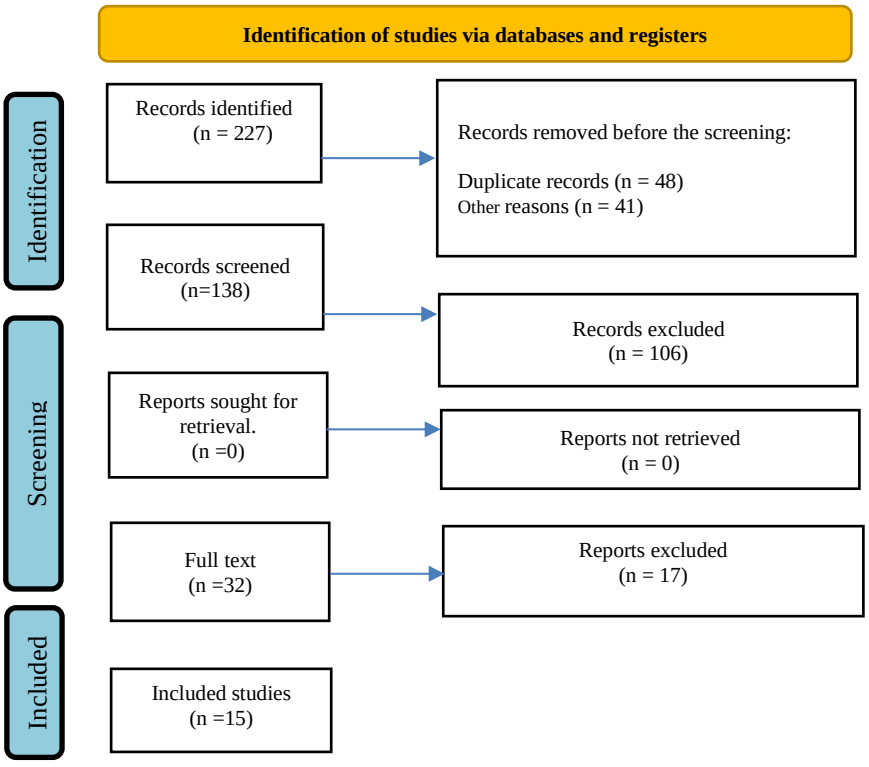

Fig. 1. PRISMA 2020 Checklist.

Table 1. Study characteristics of the included studies.

Study. Years	Study Design	Concentration of Nanoparticles (μmol/L)	Microorganisms	Antibacterial Efficacy Tests
Memon et al., 2025[20]	In vitro	0.5	p. aeruginosa	NR
Sanhueza et al.,2024[21]	In vitro	0.5	Pseudomonas aeruginosa, Staphylococcus aureus, Streptococcus mutans	NR
Madiwal et al., 2024[22]	In vitro	0.5	Streptococcus oralis, Streptococcus sanguinis, Aggregatibacter actinomycetemcomitans, and Porphyromonas gingivalis	NR
Pérez-Tanoira et al., 2022[23]	In vitro	0.5	Staphylococcus aureus or oral mixed bacterial flora composed of Streptococcus oralis	NR
Cotton et al., 2019[24]	In vitro	0.5, 2.25, 5	Escherichia coli, Streptococcus mutans, Streptococcus Mitis, and Staphylococcus aureus	MIC, MBC
Xu et al., 2019[25]	In vitro	NR	inflammatory parameters	NR
Prasetyo et al., 2018[26]	In vitro	NR	inflammatory parameters	NR
Dong et al., 2017[27]	In vitro	0.5	peri-implant infection	SEM
Diniz et al., 2016[28]	In vitro	0.5	Aggregatibacter actinomycetemcomitans	SEM
Franková et al., 2017[29]	In vitro	0.5	peri-implant infection	ELISA
Shen et al., 2017[30]	In vitro	10, 4, and 2	Staphylococcus aureus, Streptococcus mutans	SEM
Godoy-Gallardo et al., 2016[31]	In vitro	0.5	peri-implant infection	SEM
Habiboallah et al., 2014[32]	In vitro	NR	Inflammatory factors	SEM
Munger et al., 2014[33]	In vitro	NR	Inflammatory factors	SEM

Vargas-Reus et al., 2012[34]	In vitro	0.5	Prevotella intermedia, Porphyromonas gingivalis, Fusobacterium nucleatum, and Aggregatibacter actinomycetemcomitans.	MIC, MBC

Aa: Aggregatibacter actinomycetemcomitans; MIC: Minimum inhibitory (bacteriostatic) concentration; MBC: minimum bactericidal concentration; ; SEM, scanning electron microscopy; ELISA: enzyme-linked immunosorbent assay.

Antibacterial activity of AgNPs in dental implants

The antibacterial activity of AgNPs in dental implants was 60% (ES: 0.60; 95% CI, 0.54-0.67). The I^2 coefficient of 82.83% indicates high heterogeneity between studies ($p < 0.001$) (Fig. 2).

Inflammatory factors

The effectiveness of AgNPs for treating peri-implantitis was 73% (ES: 0.73; 95% CI, 0.66-0.81). The I^2 coefficient of 73.81% indicates high heterogeneity between studies ($p<0.001$) (Fig. 3). AgNPs exhibit acceptable effectiveness in reducing inflammation in the surrounding area of the implant.

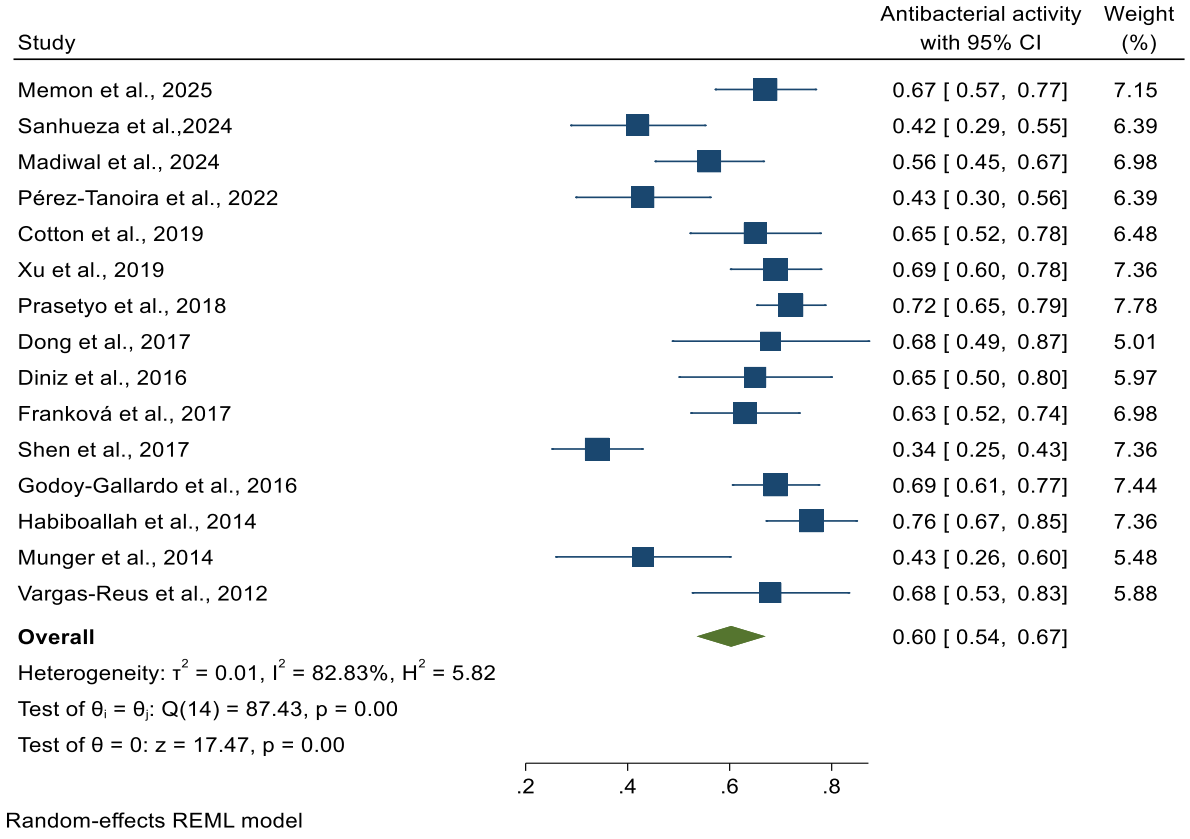

Fig. 2. The forest plot showed the Antibacterial activity of AgNPs in dental implants.

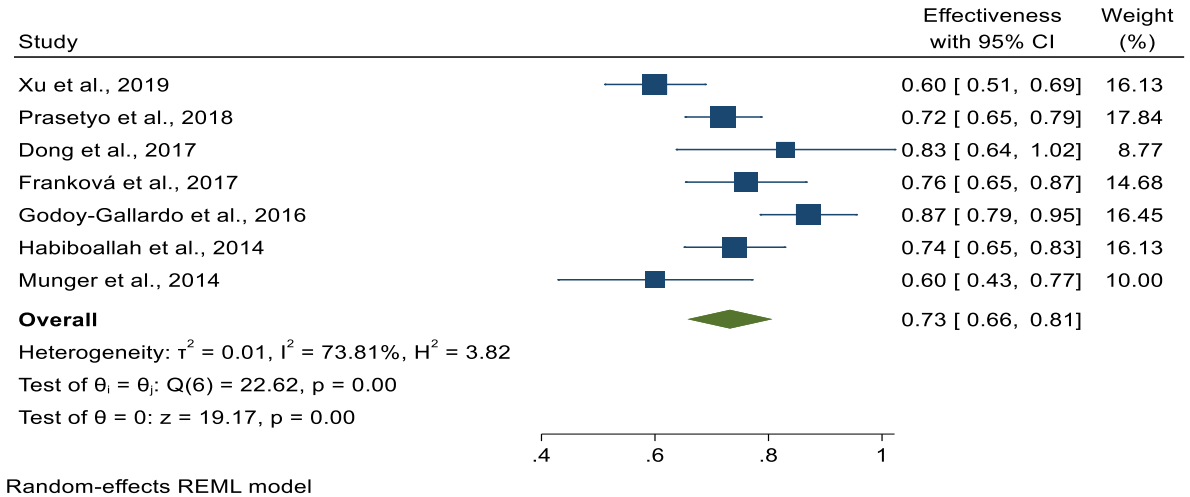

Fig. 3. The forest plot showed the Effectiveness of AgNPs for inflammatory factors.

4. Discussion

Currently, 28% to 56%of patients lose their implants due to PI.[35] Therefore, the effective prevention, control, and successful treatment of PI can have a positive impact on improving the quality of life of patients.[36] Surgery, local irrigation, and antimicrobial therapy are typically treatment options to prevent implant failure.[37] Antibiotics are generally recommended for PI along with surgical procedures. However, studies have shown that antibiotics are not effective and have not been successful in treating PI. Research suggests that nanoparticles are promising options for the treatment of PI; however, there is insufficient evidence, and most of the studies conducted are in vitro and in-vivo. The findings of these studies have shown significant antibacterial effects of nanoparticles. Metal nanoparticles have demonstrated a broad spectrum of antibacterial activity and also prevent the development of bacterial resistance.[38, 39] Study findings have shown that using silver as an antibacterial agent can be a good option in healthcare settings to prevent infections. Studies have also reported low toxicity and high antimicrobial properties for silver. Some studies have shown that silver can prevent bacteria from adhering to dental implants. AgNPs have been used as biocompatible coatings for dental implants, and it has been demonstrated that adding an appropriate amount of Ag to the surface exhibits acceptable antibacterial properties.[40, 41] Therefore, in the present study, the effectiveness of AgNPs in treating PI was investigated.

Based on the present meta-analysis, high antibacterial activity was observed for AgNPs. Other studies, consistent with the present results, have shown that the addition of AgNPs at different concentrations exhibits antibacterial activity against a variety of bacteria.[30] Recently, the use of 3D printers to create personalized and precisely dimensioned implants has received considerable attention. However, evidence has shown that these implants have poor bone bonding potential and lack antibacterial properties, often causing implant loosening and microbial infections, which can lead to PIDs.[42] Therefore, it has been suggested that the use of nanoparticles may yield good results in preventing PIDs, thereby increasing the survival rate of implants and reducing the risk of implant failure.[43, 44] The homogeneous PDA-AgNPs nanocomposite coating promoted optimal soft tissue healing and bone formation around implants, achieving a balance between cell compatibility and antibacterial activity, as indicated by the results of subcutaneous implantation, osteogenesis, cytotoxicity, and antibacterial tests. A study demonstrates that the method for synthesizing antibiotic-containing surfaces with favorable cytocompatibility and excellent antibacterial activity can be easily applied to other surfaces with similar properties. This development is expected to increase the therapeutic efficacy of silver composite-coated dental implants.[45] A green synthesis technique was used to create AgNPs in a study. The findings demonstrated that Ag-PVP nanocomposites at varying concentrations were applied to implants using a deep coating technique, exhibiting high antibacterial activity. These findings indicated that the prevalence of infection around implants could be effectively reduced by AgNPs.[46] In a review study, the potential advantages and disadvantages of using metal nanoparticles in clinical settings for the management of PID were examined to advance future therapeutic strategies for this condition, and promising results were presented.[47]

The present study had some limitations. First, the number of articles that examined effectiveness using a similar methodology and the same tools was very small, which was considered inconsistent across the above studies. Also, the antibacterial activity was examined at different concentrations of AgNPs, which in the present study was considered at a concentration of 0.5 μmol/L. Therefore, this factor can cause heterogeneity. On the other hand, not all studies provided sample sizes or were very small, which requires more robust studies. The citation and interpretation of the results from the present study should be done with caution due to the high heterogeneity of the studies. Additionally, clinical trial studies and in vitro studies with similar methodologies and more appropriate methods are needed to confirm the evidence.

5. Conclusion

Using modern methods to prevent the growth of microorganisms inside the mouth is crucial because it prevents bacterial resistance to treatment. Therefore, the present study demonstrated the acceptable effectiveness of AgNPs' antibacterial activity and reduction of inflammatory factors in the treatment of PI. AgNPs have the potential to inhibit bacterial growth and can be used as effective antibacterial and anti-inflammatory scaffolds for the treatment of PI.

Conflict of Interest

The authors declared that there is no conflict of interest.

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References

[1] Elagib MF, Alqaysi MA, Almushayt MO, Nagate RR, Gokhale ST, Chaturvedi S. Dental implants in growing patients: A systematic review and meta-analysis. Technology and Health Care. 2023 May;31(3):1051-64. https://doi.org/10.3233/THC-220581.

[2] Hom-Lay Wang D. Surgical management of significant maxillary anterior vertical ridge defects. Int J Periodontics Restorative Dent. 2016;36:329-37.

[3] Ramanauskaite A, Borges T, Almeida BL, Correia A. Dental implant outcomes in grafted sockets: a systematic review and meta-analysis. Journal of oral & maxillofacial research. 2019 Sep 5;10(3):e8. https://doi.org/10.5037/jomr.2019.10308.

[4] Barootchi S, Wang HL. Peri-implant diseases: Current understanding and management. Int J Oral Implantol (Berl). 2021 Aug 20;14(3):263-82.

[5] Wada M, Mameno T, Otsuki M, Kani M, Tsujioka Y, Ikebe K. Prevalence and risk indicators for peri-implant diseases: A literature review. Japanese Dental Science Review. 2021 Nov 1;57:78-84. https://doi.org/10.1016/j.jdsr.2021.05.002.

[6] Monje A, Kan JY, Borgnakke W. Impact of local predisposing/precipitating factors and systemic drivers on peri‐implant diseases. Clinical implant dentistry and related research. 2023 Aug;25(4):640-60. https://doi.org/10.1111/cid.13155.

[7] Schwarz F, Derks J, Monje A, Wang HL. Peri‐implantitis. Journal of clinical periodontology. 2018 Jun;45:S246-66. https://doi.org/10.1111/jcpe.12954.

[8] Cheng CD, Tsai YW, Cheng WC, Lin FG, Weng PW, Chen YW, Huang RY, Chen WL, Shieh YS, Sung CE. The referral pattern and treatment modality for peri-implant disease between periodontists and non-periodontist dentists. BMC oral health. 2023;23(1):427. https://doi.org/10.1186/s12903-023-03135-3.

[9] Xu Y, Meng F, Tang Z. Application of nanomaterials for surface modification of dental implants. J Mat Process Des. 2024;8(1):60-8. https://doi.org/10.23977/jmpd.2024.080108.

[10] Chaturvedi A, Gupta G, Kesharwani P, Shukla R. Revolutionizing periodontic care: Nano Dentistry's impact on inflammation management. Journal of Drug Delivery Science and Technology. 2024 Sep 1;99:105922. https://doi.org/10.1016/j.jddst.2024.105922.

[11] Hooshiar MH, Moghaddam MA, Kiarashi M, Al-Hijazi AY, Hussein AF, A. Alrikabi H, Salari S, Esmaelian S, Mesgari H, Yasamineh S. Recent advances in nanomaterial-based biosensor for periodontitis detection. Journal of biological engineering. 2024;18(1):28. https://doi.org/10.1186/s13036-024-00423-6.

[12] Marasli C, Katifelis H, Gazouli M, Lagopati N. Nano-based approaches in surface modifications of dental implants: a literature review. Molecules. 2024;29(13):3061. https://doi.org/10.3390/molecules29133061.

[13] Zheng H, Xu L, Wang Z, Li L, Zhang J, Zhang Q, Chen T, Lin J, Chen F. Subgingival microbiome in patients with healthy and ailing dental implants. Scientific reports. 2015 Jun 16;5(1):10948. https://doi.org/10.1038/srep10948.

[14] Sun F, Wei Y, Li S, Nie Y, Wang C, Hu W. Shift in the submucosal microbiome of diseased peri-implant sites after non-surgical mechanical debridement treatment. Frontiers in Cellular and Infection Microbiology. 2023 Jan 16;12:1091938. https://doi.org/10.3389/fcimb.2022.1091938.

[15] de Campos Kajimoto N, de Paiva Buischi Y, Mohamadzadeh M, Loomer P. The oral microbiome of peri-implant health and disease: A narrative review. Dentistry Journal. 2024 Sep 24;12(10):299. https://doi.org/10.3390/dj12100299.

[16] Niu B, Zhang G. Effects of different nanoparticles on microbes. Microorganisms. 2023 Feb 21;11(3):542. https://doi.org/10.3390/microorganisms11030542.

[17] Minetti E, editor Bone regeneration in implantology: Tooth as a graft2021: Edra.

[18] Almulhim KS, Syed MR, Alqahtani N, Alamoudi M, Khan M, Ahmed SZ, Khan AS. Bioactive inorganic materials for dental applications: a narrative review. Materials. 2022 Oct 2;15(19):6864. https://doi.org/10.3390/ma15196864.

[19] Tugwell P, Tovey D. PRISMA 2020. Journal of Clinical Epidemiology. 2021 Jun 1;134:A5-6. https://doi.org/10.1016/j.jclinepi.2021.04.008.

[20] Memon W, Naz I, Mustafa M, Ikram AM, Ali AT, Khan AS, Imtiaz A. In-Vitro Exploration of Silver Nanoparticle Coatings: Novel Insights to Biocompatibility and Antimicrobial Properties. Pakistan Journal of Medicine and Dentistry. 2025 Apr 13;14(2):353-7. https://doi.org/10.36283/ziun-pjmd14-2/053.

[21] Sanhueza C, Pavéz M, Hermosilla J, Rocha S, Valdivia-Gandur I, Manzanares MC, Beltrán V, Acevedo F. Poly-3-hydroxybutyrate-silver nanoparticles membranes as advanced antibiofilm strategies for combatting peri-implantitis. International Journal of Biological Macromolecules. 2024 Jun 1;269:131974. https://doi.org/10.1016/j.ijbiomac.2024.131974.

[22] Madiwal V, Rajwade J. Silver-deposited titanium as a prophylactic 'nano coat'for peri-implantitis. Nanoscale Advances. 2024;6(8):2113-28. https://doi.org/10.1039/D3NA00898C.

[23] Pérez-Tanoira R, Fernández-Arias M, Potel C, Carballo-Fernández R, Pérez-Castro S, Boutinguiza M, Górgolas M, Lusquiños F, Pou J. Silver nanoparticles produced by laser ablation and re-irradiation are effective preventing peri-implantitis multispecies biofilm formation. International Journal of Molecular Sciences. 2022 Oct 10;23(19):12027. https://doi.org/10.3390/ijms231912027.

[24] Cotton GC, Gee C, Jude A, Duncan WJ, Abdelmoneim D, Coates DE. Efficacy and safety of alpha lipoic acid-capped silver nanoparticles for oral applications. RSC advances. 2019;9(12):6973-85. https://doi.org/10.1039/C9RA00613C.

[25] Xu Y, Zheng B, He J, Cui Z, Liu Y. Silver nanoparticles promote osteogenic differentiation of human periodontal ligament fibroblasts by regulating the RhoA–TAZ axis. Cell Biology International. 2019 Aug;43(8):910-20. https://doi.org/10.1002/cbin.11180.

[26] Prasetyo BC, Sugiharti RJ, Mahendra I, Halimah I, Widyasar EM, Rusminah N, Mustika I. Evaluation of silver nanoparticles addition in periodontal dressing for wound tissue healing by 99mTc-ciprofloxacin. Journal of Young Pharmacists. 2019;11(1):17. https://doi.org/10.5530/jyp.2019.11.4.

[27] Dong Y, Ye H, Liu Y, Xu L, Wu Z, Hu X, Ma J, Pathak JL, Liu J, Wu G. pH dependent silver nanoparticles releasing titanium implant: A novel therapeutic approach to control peri-implant infection. Colloids and Surfaces B: Biointerfaces. 2017 Oct 1;158:127-36. https://doi.org/10.1016/j.colsurfb.2017.06.034.

[28] Diniz IM, Chen C, Ansari S, Zadeh HH, Moshaverinia M, Chee D, Marques MM, Shi S, Moshaverinia A. Gingival mesenchymal stem cell (GMSC) Delivery system based on RGD‐coupled alginate hydrogel with antimicrobial properties: a novel treatment modality for peri‐implantitis. Journal of Prosthodontics. 2016 Feb;25(2):105-15. https://doi.org/10.1111/jopr.12316.

[29] Franková J, Pivodová V, Vágnerová H, Juráňová J, Ulrichová J. Effects of silver nanoparticles on primary cell cultures of fibroblasts and keratinocytes in a wound-healing model. Journal of applied biomaterials & functional materials. 2016 Apr;14(2):137-42. https://doi.org/10.5301/jabfm.5000268.

[30] Shen XT, Zhang YZ, Xiao F, Zhu J, Zheng XD. Effects on cytotoxicity and antibacterial properties of the incorporations of silver nanoparticles into the surface coating of dental alloys. Journal of Zhejiang University-SCIENCE B. 2017 Jul;18(7):615-25. https://doi.org/10.1631/jzus.B1600555.

[31] Godoy-Gallardo M, Manzanares-Céspedes MC, Sevilla P, Nart J, Manzanares N, Manero JM, Gil FJ, Boyd SK, Rodríguez D. Evaluation of bone loss in antibacterial coated dental implants: An experimental study in dogs. Materials Science and Engineering: C. 2016 Dec 1;69:538-45. https://doi.org/10.1016/j.msec.2016.07.020.

[32] Habiboallah G, Mahdi Z, Majid Z, Nasroallah S, Taghavi AM, Forouzanfar A, et al. Enhancement of gingival wound healing by local application of silver nanoparticles periodontal dressing following surgery: a histological assessment in animal model. Modern Research in Inflammation. 2014.

[33] Munger MA, Radwanski P, Hadlock GC, Stoddard G, Shaaban A, Falconer J, Grainger DW, Deering-Rice CE. In vivo human time-exposure study of orally dosed commercial silver nanoparticles. Nanomedicine: Nanotechnology, Biology and Medicine. 2014 Jan 1;10(1):1-9. https://doi.org/10.1016/j.nano.2013.06.010.

[34] Vargas-Reus MA, Memarzadeh K, Huang J, Ren GG, Allaker RP. Antimicrobial activity of nanoparticulate metal oxides against peri-implantitis pathogens. International journal of antimicrobial agents. 2012 Aug 1;40(2):135-9. https://doi.org/10.1016/j.ijantimicag.2012.04.012.

[35] Zimmer JM. Risk Indicators for Peri-Implant Diseases and Peri-Implantitis Severity: A Cross-Sectional Study on Implants with 5 to 10 Years of Loading 2025. https://dx.doi.org/10.7302/26335.

[36] Chang JW. New Era of the Peri-Implant Diseases. 2025. https://dx.doi.org/10.5772/intechopen.1009264.

[37] Alterman M, Casap N. The Approach to Periimplantitis. Oral and Maxillofacial Surgery Clinics. 2025 Feb 1;37(1):85-97.

[38] Shandila P, Mahatmanto T, Hsu JL. Metal-Based Nanoparticles as Nanopesticides: Opportunities and Challenges for Sustainable Crop Protection. Processes. 2025 Apr 23;13(5):1278. https://doi.org/10.3390/pr13051278.

[39] Sánchez-López E, Gomes D, Esteruelas G, Bonilla L, Lopez-Machado AL, Galindo R, Cano A, Espina M, Ettcheto M, Camins A, Silva AM. Metal-based nanoparticles as antimicrobial agents: an overview. Nanomaterials. 2020 Feb 9;10(2):292. https://doi.org/10.3390/nano10020292.

[40] Negussie AH, Dreher MR, Johnson CG, Tang Y, Lewis AL, Storm G, Sharma KV, Wood BJ. Synthesis and characterization of image-able polyvinyl alcohol microspheres for image-guided chemoembolization. Journal of Materials Science: Materials in Medicine. 2015 Jun;26(6):198. https://doi.org/10.1007/s10856-015-5530-3.

[41] Ferraris S, Spriano SJ. Antibacterial titanium surfaces for medical implants. Materials Science and Engineering: C. 2016 Apr 1;61:965-78. https://doi.org/10.1016/j.msec.2015.12.062.

[42] Li Z, Wang Q, Liu G. A review of 3D printed bone implants. Micromachines. 2022 Mar 27;13(4):528. https://doi.org/10.3390/mi13040528.

[43] Feng P, He R, Gu Y, Yang F, Pan H, Shuai C. Construction of antibacterial bone implants and their application in bone regeneration. Materials Horizons. 2024;11(3):590-625. https://doi.org/10.1039/D3MH01298K.

[44] Venkatesan K, Tchekep AK, Anadebe VC, Mathew AM, Sreya PV, Rajendran A, Barik RC, Pattanayak DK. Development of bioactive and antimicrobial nano-topography over selective laser melted Ti6Al4V implant and its in-vitro corrosion behavior. Journal of the Mechanical Behavior of Biomedical Materials. 2024 Jan 1;149:106210. https://doi.org/10.1016/j.jmbbm.2023.106210.

[45] Wang S, Wu Z, Wang Y, Hong H, Zhang L, Chen Z, Zhang P, Chen Z, Zhang W, Zheng S, Li Q. A homogeneous dopamine–silver nanocomposite coating: striking a balance between the antibacterial ability and cytocompatibility of dental implants. Regenerative Biomaterials. 2023 Jan 1;10:rbac082. https://doi.org/10.1093/rb/rbac082.

[46] Abdulkadhim TM, Al Khaffaf I, Shinen MH. The effect of changing the concentration of silver nanoparticles on the antibacterial properties of silver-PVP composite-coated implants. Journal of Iranian Medical Council. 2022;6(1). https://doi.org/10.18502/jimc.v6i1.11851.

[47] Hosseini Hooshiar M, Mozaffari A, Hamed Ahmed M, Abdul Kareem R, Jaber Zrzo A, Salah Mansoor A, H. Athab Z, Parhizgar Z, Amini P. Potential role of metal nanoparticles in treatment of peri-implant mucositis and peri-implantitis. BioMedical Engineering OnLine. 2024 Oct 12;23(1):101. https://doi.org/10.1186/s12938-024-01294-0.

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