Review Article

Periodontics Revolution - The Nanotechnology Era: A Review

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Abstract

Nanotechnology become a revolutionary influence in treating periodontal disease, offering new methods in preventing, diagnosing, and treating these conditions. This review examines how nanotechnology enhances tissue regeneration, manages biofilms, local drug delivery, addresses tooth sensitivity, resolution of inflammation etc. With their unique chemical, biological and physical properties at the nano level, nanomaterial have transformed dental practices by allowing precise control over material interactions at atomic scales. These advancements show potential for improving clinical outcomes in periodontics, yet they also present ethical, social, and health challenges that require careful consideration. Overall, recent developments in nanotechnology applications in periodontal care indicate a potential shift in dental treatment methods.

Keywords: Nanotechnology, Nanomaterials, Periodontal disease, Biofilms ,Oral hygiene .

Introduction

The use of nano-technology involves the application of nanomaterials and techniques to improve dental treatments, diagnostics and preventive care. It enhances dental care by utilizing nanomaterials and techniques to improve restorations, enable targeted drug delivery and detect oral diseases. Nano-technology offers potential advancements in precision, efficacy and patient comfort in treatment.

The word “nano “originated from Greek word “dwarf”.[1] Nanotechnology is not merely the study of tiny objects, but it involves the research and development of materials, devices and systems that exhibit distinct properties that differ from those found at larger scales. Therefore, nanotechnology can best be described as a broad amalgamation of technologies from diverse fields such as biochemistry, physics, engineering etc each offering different characteristics and applications.[2]

Periodontitis is a chronic inflammation affecting the tooth supporting structures, including the gingiva, periodontal ligament, cementum and alveolar bone.[3] Periodontitis is a serious gum infection that damages the soft tissue, causes loss of attachment, destroys the periodontal ligament and bone supporting the teeth if left untreated.[4]

Nanotechnology is emerging as a promising tool for diagnostics, prognosis, prediction and treatment across various fields. Recent advances in nanotechnology are providing effective solutions for a range of dental disorders, including periodontal disease.[5]

For many years, achieving the complete regeneration of periodontal tissues has been a significant challenge. However, recent advancements in nanomaterials and nanotechnology now offer promising opportunities for treating periodontal diseases.[6] This technology in periodontics employs nanomaterials and nanodevices for diagnosing, treating and preventing periodontal diseases. It's now a key part of periodontics, including applications like nanodentifrices, dental hypersensitivity treatments, anti-biofilm methods, drug delivery systems etc.[7]

This review summarizes the role of nanotechnology in periodontics, its use in preventing and treating oral diseases and recent updates on periodontal therapy.

History

In the year 1867 the concept of nano technology was introduced by James Clerk Maxwell. Richard Zsigmondy made remarkable strides in 1914 by conducting the first measurement and observations in nanoparticles. Richard Feynman, a Nobel Prize- winning physicist put forward the concept of nano technology during this lecture on “There's plenitude of Room at the Bottom”. The meeting took place in 1959 at American Physical Society, California. The term "nano-technology" was officially coined by Norio Taniguchi in 1974. He defined it as a technology involving the processing, separation, connection and conformation of accoutrements by individual tittles or molecules.[8] Eric Drexler's influential book "Engines of Creation," published in 1986, envisioned a future where nanotechnology could assemble atoms and molecules to create nanocircuits and nanomachines. Robert Freitas Jr., a trailblazer in nanomedicine, defined the field as employing nanorobots for diagnosing, treating, and preventing diseases. In 2000, he introduced the concept of "nanodentistry," aiming to use nanomaterials, biotechnology, and nanorobotics to optimize oral health.[9]

Nanoparticles

Nanotechnology has evolved over the decades, revolutionizing developments in, biotechnology, and medicine. They are defined by their size, which should be less than 100nm in one dimension. This includes particles smaller than 100nm, films thinner less than100 nm, fibers with diameters under 100 nm, and composites combining these components. Nanomaterials exceed conventional materials in stiffness, toughness, transparency, resistance to heat, solvents and abrasion. Additionally, their distinctive optical, electro-optical, chemical, and magnetic properties cater to the increasing demands of nanotechnology in medical care.[10]

A wide range of nanoparticles are utilized in biomedical applications, includes nanopores, nanotubes, quantum dots, dendrimers, liposomes, nanorods, fullerenes (Buckyballs), nanospheres, nanowires, nanobelts, nanorings, nano capsules, and numerous others. These nanoparticles, include metallic, semiconductor and organic molecule that are employed in various sizes, shapes and structures for biomedical purposes.[11]

Nanomaterials are classified based on their dimensions as sheets in one dimension, nanowires and nanotubes in two dimensions, quantum dots in three dimensions. Nano-particles can be synthesized through different approaches that is top down and bottom-up approaches. The top-down method involves reducing particle size through grinding or milling after conventional manufacturing, as seen in nanocomposites, nano encapsulation, and nano coatings on implants. Conversely, the bottom-up approach directly synthesizes nanoparticles from molecular levels, assembling them into larger structures.[12]

The different nanoparticle used in dentistry are summarized, and their applications are shown in Figure 1 and Figure 2.[13]

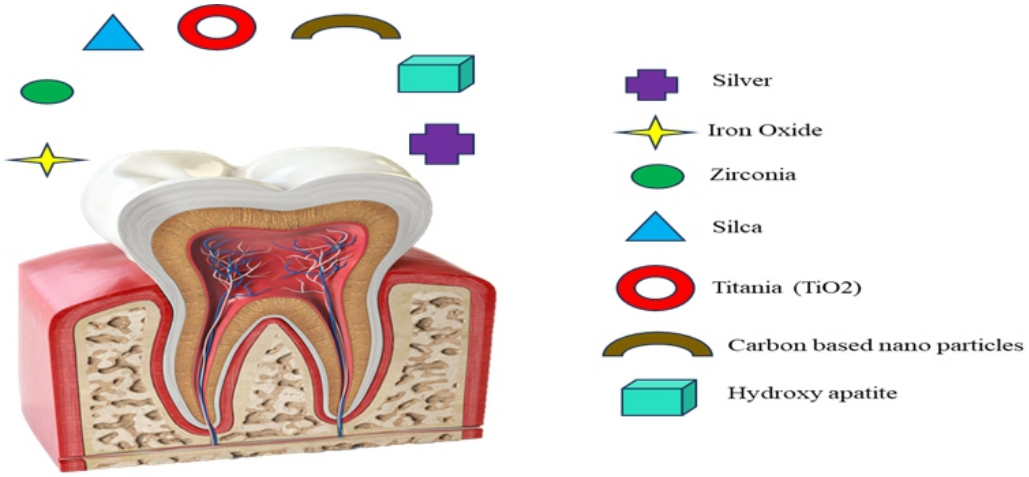

Figure 1. Different nanoparticles used in dentistry

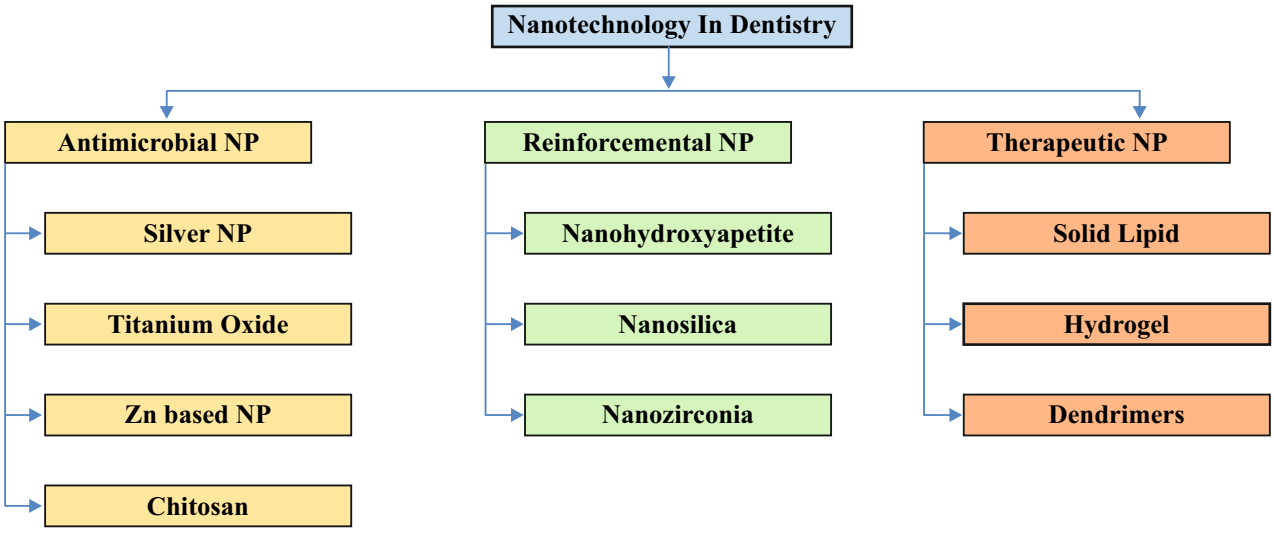

Figure 2. Dental applications of nanoparticles

Characteristics Of Nanoparticles

- Nanoparticles have enhanced mechanical properties including increased toughness, stiffness, transparency, and resistance to scratches, abrasion, solvents, and heat, while also reducing gas permeability.
- They exhibit distinct chemical, optical, magnetic, and electro-optical characteristics that differ from both individual molecules and bulk materials.[14]
- Nanoparticles show significant surface effects, size effects, and quantum effects, contributing to their superior performance compared to conventional materials.
- One notable characteristic is their ability to self-assemble, autonomously arranging into patterns or structures without external intervention.[10]
- Nanoparticles has hight surface area than mass compared to larger particles.[2]

Applications Of Nanoparticles in Periodontics

1. Chronic Periodontitis

The advancement in nanotechnology has introduced new therapeutic materials for periodontal disease. Previous research has highlighted the potent antibacterial properties of silver nanoparticles, making them a viable option for nonsurgical periodontal therapies. Kadam et al. proposed that incorporating silver nanoparticle gel alongside scaling and root planing could potentially offer superior effectiveness compared to tetracycline gel in managing chronic periodontitis.[15] Nanoparticles, due to their chemical compositions, particle size, surface charge, and other properties, enhance retention by interacting with the biofilm matrix, which in turn boosts their antimicrobial effectiveness.[16]

Both silver nanoparticles and zinc oxide nanoparticles exhibit strong antimicrobial properties, aiding in the reduction of bacterial load in periodontal pockets. Additionally, chitosan nanoparticles are being investigated for their potential to disrupt bacterial cell walls.Chitosan showed the highest antimicrobial effect, damaging 95% of S. mutans cells by affecting their cell membranes.[17]

2. Local Drug Delivery

Nanoparticles are designed to deliver antibiotics or anti-inflammatory agents directly to periodontal pockets, enhancing treatment effectiveness while minimizing systemic side effects. Nanocarriers such as liposomes, dendrimers, and micelles improve drug penetration and retention at the intended site of action.[18]

Recently, Pinon-Segundo et al. have developed and introduced triclosan-loaded nanoparticles using the emulsification–diffusion process to make a delivery system suitable for treating periodontal disease. These triclosan nanoparticles act as a homogeneous polymer matrix-type delivery system, where the drug (triclosan) is molecularly dispersed.[10] Controlled drug release can be achieved using biodegradable nanospheres. An example is Arestin, where tetracycline is incorporated into microspheres for local drug delivery to a periodontal pocket. Hollow spheres, core–shell structures, nanotubules, and nanocomposites can also be used as periodontal drug-delivery systems.[2]

3. Subgingival Irrigation

Hayakumo et al. described the use of ozone nano-bubble water for subgingival irrigation produced through nano-bubble technology. Their study demonstrated that this treatment can be an effective adjunct to periodontal therapy due to its enhanced antibacterial activity. Ozone nano -bubble water have antimicrobial effect, high safety, long storage stability etc that make it suitable for periodontal therapy.[19]

Sushree Ambika Sahu and Saurav Panda found that subgingival delivery of propolis nanoparticles, as an adjunct to Scaling and Root Planing shows promising results and can significantly improve periodontal treatment outcomes.[20]

4. Oral Hygiene Maintenance

Nanorobots, also known as dentifrobots, can be applied as mouthwash or toothpaste and remain on the occlusal surfaces of teeth. With their rapid and continuous movement (1–10 μm/second) across supra and subgingival surfaces, they effectively remove organic residues and prevent calculus buildup. These nanorobots are designed to be safely deactivated upon swallowing.[21]

Nanorobots are being incorporated into mouthwash to detect and eradicate harmful bacteria responsible for gingivitis and periodontitis, while promoting the growth of beneficial oral bacteria. They help to identify and remove food particles, plague, tartar from teeth making a clean and debris free mouth. Future dental products may employ hollow spheres, core-shell structures, nanotubes, and nanocomposites for precise delivery of medications aimed at treating periodontal issues. These nanorobots are expected to continuously remove both surface and deep dental deposits, providing ongoing protection against bad breath by eliminating bacteria that produce unpleasant odours.[22]

5. Dentinal Hypersensitivity

Dentinal hypersensitivity is a common concern, treated with products containing potassium, strontium, oxalates, fluoride salts etc. Toothpastes with carbonated hydroxyapatite nanocrystals are also being studied. These nanocrystals bind to enamel and dentine apatite, creating a biomimetic coating that reduces plaque formation, prevents decay, revitalizes teeth, and seals dentinal tubules, effectively alleviating hypersensitivity. Future advancements in these products promise breakthroughs in treating dentinal hypersensitivity.[23]

Jian Yu and Hongye Yang discovered that toothpastes containing nano hydroxyapatite show promising results in reducing dentinal hypersensitivity. Dental nano robots which usually seals the dentinal tubules shows prolonged results.[24]

6. Bone Regeneration

Nanostructured materials, such as nanofibers, nanoparticles, and nanocomposites, can mimic the natural structure of bone and provide a scaffold for bone cells to adhere and grow. Nanoparticles deliver growth factors, stem cells, or therapeutic agents directly to bone defects, enhancing healing and regeneration processes.

Bone is a naturally occurring composite with organic components strengthened by hydroxyapatite crystals, making it a nanostructured material. Nanotechnology holds significant promise in repairing bone defects by enabling the development of nano-bone graft materials. These grafts must exhibit properties comparable to conventional bone grafts. Since the surface area to mass ratio is high, it is beneficial for treating intrabony defects.[25]

7. Photodynamic Therapy

Nanoparticles in photodynamic therapy (PDT) provide a novel approach to treating periodontal diseases by using light-activated photosensitizers to generate reactive oxygen species (ROS) that selectively kill bacteria and modulate inflammation. They enhance PDT effectiveness through targeted delivery, improving precision and efficacy while minimizing damage to healthy tissue, and penetrate deeper into periodontal pockets for comprehensive bacterial eradication. Nanoparticles protect photosensitizers from degradation, prolonging their effectiveness. They can also be combined with other therapeutic agents for synergistic effects against infection and inflammation, while disrupting bacterial biofilms resistant to conventional treatments.

De Freitas and Calixto found that antimicrobial photodynamic therapy (aPDT) using methylene blue-loaded poly (lactic-co-glycolic acid) (PLGA)nanoparticles with red light at 660 nm eliminated about 25% more bacteria in biofilms than free methylene blue and improved the gingival bleeding index (GBI) more than scaling and root planing (SRP) alone after three months. This indicates that PLGA nanoparticles encapsulated with methylene blue could be a promising adjunct in antimicrobial periodontal treatment.[26] Ongoing research aims to optimize nanoparticle features to enhance PDT outcomes in periodontal therapy, offering more precise and effective treatments for periodontal diseases.

8. Dental Implants

Insufficient bone formation around dental implants is a common reason for their failure, so modifying the implant surface with nanoscale textures or coatings can help promote better and quicker bone integration and healing around implants.[27]

Nanomaterials are ideal for coating titanium-based dental implants because of their distinctive properties. The use of nanoparticles as coatings on Ti-based implants aims to enhance osseointegration and antimicrobial effectiveness, thereby improving the overall success rate of the implants.[28] Nanocoatings on dental implants and other devices can prevent bacterial colonization and biofilm formation, reducing the risk of infections around implants.

Nanoparticles are being increasingly studied in peri-implant therapy for their ability to enhance osseointegration, reduce microbial colonization, and enhance the longevity and success of dental implants. Silver nanoparticles, recognized for their safety and potent antimicrobial properties, are being evaluated as a supplemental treatment option for periodontal and peri-implant conditions.[29]

Challenges Encountered in Nanodentistry[30]

- Assembly of molecular-scale components and achieving precise positioning is crucial.
- Developing cost-effective techniques for mass-production of materials in nanotechnology.
- Ensuring that nanomaterials used are biocompatible with oral tissues is crucial to prevent adverse reactions.
- Efficiently delivering nanoparticles to specific areas within the periodontal tissues without dispersion or degradation is challenging.
- It is crucial to address social concerns including public acceptance, ethical considerations, regulatory frameworks, and ensuring human safety when deploying nanotechnologies.

Conclusion

Nanotechnology is increasingly vital in diagnosing and managing treatments. While achieving full regeneration of periodontal tissues may not be feasible soon, recent advances in nanomaterials and technology show promise for commercial applications in diagnosing and managing gum diseases. It holds immense promise in revolutionizing periodontal treatment by offering targeted drug delivery systems, improved diagnostic tools, and enhanced biomaterials for tissue regeneration. Nanotechnology has the potential to aid periodontal care by providing treatment options that are more accurate, effective, and better suited to patient needs

Research is actively working on developing specific nanomaterials to enhance dental care. Nano dentistry explores novel nanomaterials and devices across various human activities. Despite being in early stages, clinical studies hold potential to significantly enhance dental diagnosis, treatment planning, and tissue regeneration.

Further research and trials are necessary to expand the application of nanotechnology in oral health and dental care.

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References

1. Jandt KD, Watts DC. Nanotechnology in dentistry: Present and future perspectives on dental nanomaterials. Dental Materials. 2020 Nov 1;36(11):1365-78.
2. Sharma VK, Trivedi H, Bey A, Gupta N. Nanotechnology: rise of a new era in periodontics. Univ. J. Dental Sci. 2016.
3. Page RC, Engel LD, Narayanan AS, Clagett JA. Chronic inflammatory gingival and periodontal disease. Jama. 1978 Aug 11;240(6):545-50.
4. Zupancic S, Kocbek P, Baumgartner S, Kristl J. Contribution of nanotechnology to improved treatment of periodontal disease. Current pharmaceutical design. 2015 Jul 1;21(22):3257-71.
5. Aminu N, Chan SY, Toh SM. Roles of nanotechnological approaches in periodontal disease therapy. Journal of Applied Pharmaceutical Science. 2017 Jul 30;7(7):234-42.
6. RG SM, Rana A. Nanotechnology in periodontal management. Journal of Advanced Oral Research. 2015 Jan;6(1):1-8.
7. Arjunkumar R. Nanomaterials for the management of periodontal diseases. Dental Applications of Nanotechnology. 2018:203-15.
8. Verma S, Chevvuri R, Sharma H. Nanotechnology in dentistry: unleashing the hidden gems. Journal of Indian Society of Periodontology. 2018 May 1;22(3):196-200.
9. Singhal D, Aggarwal P, Bali S, Pal K. Nanotechnology in periodontics: A review. Santosh University Journal of Health Sciences. 2021 Jul 1;7(2):6-10.
10. Kong LX, Peng Z, Li SD, Bartold PM. Nanotechnology and its role in the management of periodontal diseases. PERIODONTOLOGY 2000. 2006 Feb 1;40(1):184.
11. Rao KP, Kumar JS. Nanotechnology in dentistry. Kerala Dent J. 2013 Jan;36:56-9. Priyadarsini S, Mukherjee S, Mishra M. Nanoparticles used in dentistry: A review. Journal of oral biology and craniofacial research. 2018 Jan 1;8(1):58-67.
12. Bhardwaj A, Bhardwaj A, Misuriya A, Maroli S, Manjula S, Singh AK. Nanotechnology in dentistry: Present and future. Journal of international oral health: JIOH. 2014 Feb;6(1):121.
13. Priyadarsini S, Mukherjee S, Mishra M. Nanoparticles used in dentistry. Journal of oral biology and craniofacial research. 2018 Jan 1;8(1):58-67.
14. Gowri SP, Saurabh RJ, Preeti PK, Shruti SD. Upheaval of Nanoscience in Periodontics. Journal of Datta Meghe Institute of Medical Sciences University. 2021 Apr 1;16(2):393-6.
15. Kadam P, Mahale S, Sonar P, Chaudhari D, Shimpi S, Kathurwar A. Efficacy of silver nanoparticles in chronic periodontitis patients: a clinico-microbiological study. Iberoamerican Journal of Medicine. 2020;2(3):142-7.
16. Silvestre AL, Di Filippo LD, Besegato JF, de Annunzio SR, de Camargo BA, de Melo PB, de Souza Rastelli AN, Fontana CR, Chorilli M. Current applications of drug delivery nanosystems associated with antimicrobial photodynamic therapy for oral infections. International Journal of Pharmaceutics. 2021 Jan 5;592:120078.
17. Sen D, Patil V, Smriti K, Varchas P, Ratnakar R, Naik N, Kumar S, Saxena J, Kapoor S. Nanotechnology and nanomaterials in dentistry: present and future perspectives in clinical applications. Engineered Science. 2022 Apr 29;20:14-24.
18. Gu W, Wu C, Chen J, Xiao Y. Nanotechnology in the targeted drug delivery for bone diseases and bone regeneration. International journal of nanomedicine. 2013 Jun 25:2305-17.
19. Hayakumo S, Arakawa S, Mano Y, Izumi Y. Clinical and microbiological effects of ozone nano-bubble water irrigation as an adjunct to mechanical subgingival debridement in periodontitis patients in a randomized controlled trial. Clinical oral investigations. 2013 Mar; 17:379-88.
20. Sahu SA, Panda S, Das AC, Mishra L, Rath S, Sokolowski K, Kumar M, Mohanty R, Nayak R, Satpathy A, Lapinska B. Efficacy of Sub-Gingivally Delivered Propolis Nanoparticle in Non-Surgical Management of Periodontal Pocket: A Randomized Clinical Trial. Biomolecules. 2023 Oct 26;13(11):1576.
21. Abou Neel EA, Bozec L, Perez RA, Kim HW, Knowles JC. Nanotechnology in dentistry: prevention, diagnosis, and therapy. International journal of nanomedicine. 2015 Oct 8:6371-94.
22. Vaishali S, Nashra K. Nanotechnology in periodontics: a review. J. Res. Med. Dent. Sci. 2021 Feb;9:339-44.

23. Khetawat S, Lodha S. Nanotechnology (nanohydroxyapatite crystals): recent advancement in treatment of dentinal hypersensitivity. J Interdiscipl Med Dent Sci. 2015;3:181.

24. Yu J, Yang H, Li K, Lei J, Zhou L, Huang C. A novel application of nanohydroxyapatite/mesoporous silica biocomposite on treating dentin hypersensitivity: an in vitro study. Journal of dentistry. 2016 Jul 1;50:21-9.

25. Schleyer TL. Nanodentistry: Fact or fiction?. The Journal of the American Dental Association. 2000 Nov 1;131(11):1567-8.

26. De Freitas LM, Calixto GM, Chorilli M, Giusti JS, Bagnato VS, Soukos NS, Amiji MM, Fontana CR. Polymeric nanoparticle-based photodynamic therapy for chronic periodontitis in vivo. International journal of molecular sciences. 2016 May 20;17(5):769.

27. Thakral GK, Thakral R, Sharma N, Seth J, Vashisht P. Nanosurface–the future of implants. Journal of clinical and diagnostic research: JCDR. 2014 May;8(5):ZE07.

28. Parnia F, Yazdani J, Javaherzadeh V, Dizaj SM. Overview of nanoparticle coating of dental implants for enhanced osseointegration and antimicrobial purposes. Journal of Pharmacy & Pharmaceutical Sciences. 2017 May 29;20:148 60.

29. Siddiqi A, Zafar S. Scope of Silver Nanoparticles in Periodontal and Peri-Implant Wound Healing: A Systematic Review of Translation Research. Essentials of Dentistry. 2023 Jun 26;2(2):55-65.

30. Kumar, Saravana R1; Vijayalakshmi, R2, Nanotechnology in dentistry. Indian Journal of Dental Research 17(2):p 62-5, Apr–Jun 2006. | DOI: 10.4103/0970-9290.29890.