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Role of nanotechnology in oral medicine: A review

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Abstract

Nanotechnology is revolutionizing dentistry, enhancing oral health care with greater precision and effectiveness. It works with super tiny materials, called nanoparticles, that are 1-100 nanometers small. These are used in oral medicine and radiology to improve diagnosis, treatments, and prevention. Things like nanosensors, quantum dots, and nanocomposites help detect and fix problems faster. Nanotechnology also fights harmful biofilms and develops advanced therapeuticsfor oral health. While it's exciting, there are still challenges to make it common in dental care.

Keywords: Nanotechnology; Nanoparticles; Quantum Dots; Nanobiosensors; Biofilms; Nanocomposites; Therapeutics.

1. Introduction

Nanotechnology represents a transformative leap in science, ushering humanity into a new era of technological innovation. The term "nano," derived from the Greek word for "dwarf," refers to one-billionth of a meter, with nanoscale structures ranging from 1 to 100 nanometers. To put this in perspective, a human hair is approximately 100,000 nanometers thick, while the size of atoms is around 0.1 nanometers. Nanotechnology involves the direct manipulation of materials at this incredibly small scale, allowing for precise control over the structure and properties of matter.[1] This field aims to analyze, manufacture, and develop devices at the nanoscale, creating materials and systems with unique physical, chemical, andbiological properties distinct from those of larger structures. The conceptual foundation of nanotechnology was laid in 1959 by physicist Richard P. Feynman in his seminal speech, "Thereis plenty of room at the bottom," where he envisioned the potential of manipulating matter at the atomic level.

Since then, advancements in both theoretical and experimental aspects of nanotechnology have rapidly evolved, promising revolutionary applications across various fields, including dentistry.[2] The integration of nanotechnology into dentistry holds the potential for groundbreaking improvements in diagnostics, treatment, and prevention, marking the beginning of a pioneering era in dental science. Nanotechnology is significantly transformingoral medicine by enhancing diagnostic, therapeutic, and preventive strategies. The integrationof nanoparticles in dentistry has led to innovative solutions that address various oral health challenges. In terms of diagnostic advancements, nanoparticles improve diagnostic imaging, allowing for earlier and more precise detection of dental diseases, such as dental caries and periodontal disease, thereby enhancing overall diagnostic accuracy Therapeutically, nanotechnology facilitates targeted drug delivery systems, particularly in treating oral cancers,by improving drug selectivity and reducing side effects.[3]

Additionally, nanomaterials enhance restorative dentistry through improved mechanicalproperties of dental materials and promote tissue regeneration In preventive measures, the development of nano-based oral care products aids in preventing oral diseases, including candidiasis and denture stomatitis.[4] Nanotechnology also plays a role in pain management and alleviating dental hypersensitivity, contributing to improved patient comfort.[5] This articlereviews the

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multifaceted role of nanotechnology in oral medicine, highlighting its impact on diagnostics, therapeutics, and prevention.

2. Nanoparticles for targeted drug delivery

Nanoparticles represent a significant advancement in drug delivery systems, particularly in oral medicine, where they offer targeted delivery to oral tissues, enhancing therapeutic efficacy and minimizing side effects. By leveraging their nanoscale dimensions, these particlescan effectively navigate biological barriers and concentrate therapeutic agents at specific sites,improving treatment outcomes. Nanoparticles are engineered to deliver drugs directly to theaffected oral tissues, such as those involved in dental infections, oral cancers, or inflammatoryconditions.[6] This targeted approach ensures that the therapeutic agents are concentrated where they are needed most, reducing the need for high doses and consequently, the risk ofsystemic side effects. For instance, nanoparticles can be designed to respond to specific stimuliin the oral environment, such as pH or enzyme activity, enabling controlled release of the drugprecisely at the target site. Liposomes are spherical vesicles with a phospholipid bilayer that can encapsulate both hydrophilic and hydrophobic drugs.

In oral medicine, liposomes are used to enhance the delivery of antimicrobial agents, anti- inflammatory drugs, and local anesthetics. They can improve drug stability, increase bioavailability, and achieve sustained release, thereby enhancing therapeutic efficacy and patient compliance. Local nanoanesthesia involves a colloidal suspension containing millions of active analgesic micron-sized dental robots, which are applied to the patient's gingiva. Uponcontact with the crown or mucosal surface, the mobile nanorobots travel through the gingivalsulcus, lamina propria, and dentinal tubules to reach the pulp. Once inside the pulp, the dentist can command the nanorobots to block sensitivity in the targeted tooth for treatment.After the dental procedure is finished, the dentist directs the nanorobots to restore normal sensation, release control of the nerve signals, and exit the tooth using the same pathways they entered.

3. Nanotechnology in improving diagnostic techniques

Nanotechnology has significantly advanced diagnostic techniques in oral medicine by enhancing the sensitivity and specificity of disease detection. One of the most notable applications is in the early detection of oral cancers and diseases. Nanoparticles, due to theirunique size and surface properties, can be engineered to target specific biomarkers associated with oral diseases.[9] This targeted approach allows for the detection of disease at a much earlier stage than traditional methods. For instance, quantum dots, which are semiconductornanoparticles, are used in imaging techniques to detect and visualize oral cancer cells with high precision. Their fluorescent properties enable real-time observation of cellular processesand tumor margins, aiding in early diagnosis and better treatment planning. Similarly, gold nanoparticles can be conjugated with antibodies or other targeting molecules to bind specifically to cancerous cells or abnormal tissue, enhancing the accuracy of diagnostic imaging and histopathology.

Nanobiosensors represent a cutting-edge application of nanotechnology in diagnostics, particularly for detecting biomarkers in oral fluids. These nanoscale sensors are designed to recognize and bind to specific biological molecules associated with oral diseases, such as cancer, periodontal disease, or bacterial infections. Nanobiosensors can detect cancer biomarkers in saliva or other oral fluids, providing a non-invasive and efficient method for early cancer detection. For example, nanosensors functionalized with antibodies specific to oral cancer markers can identify trace amounts of these markers in saliva, potentially leadingto earlier and more accurate diagnosis.[10] Nanobiosensors can be used to measure biomarkersrelated to periodontal disease, such as inflammatory cytokines or specific bacterial DNA. By detecting these biomarkers in oral fluids, these sensors can offer insights into the presence and severity of periodontal disease, enabling timely intervention and monitoring. Nanosensors can differentiate between various bacterial species based on their unique surface interactions or genetic material, aiding in the rapid diagnosis of bacterial infections inthe oral cavity.[11]

4. Nanoparticle-based therapies and regenerative medicine

Nanoparticles have revolutionized the treatment of various oral diseases through their abilityto deliver therapeutic agents with high precision. Their unique properties allow for targeted and controlled treatment of conditions such as bacterial infections, oral cancers, and inflammatory diseases. Nanoparticles, such as silver and zinc oxide nanoparticles, possess inherent antimicrobial properties that make them effective in treating bacterial infections in the oral cavity.[12] These nanoparticles can be incorporated into dental materials, mouthwashes, or topical treatments to combat bacterial pathogens. Their high surface area and ability to release antimicrobial agents in a controlled manner enhance their efficacy in managing infections and reducing the risk of antibiotic resistance. Oral Cancers: In the treatment of oral

cancers, nanoparticles can be used to deliver chemotherapeutic agents specifically to tumor cells while sparing healthy tissues.[13] Nanotechnology plays a crucial rolein regenerative medicine, particularly in the field of oral tissue engineering and regeneration.The use of nanomaterials enhances the repair and regeneration of damaged or diseased oraltissues.[14]

Nanotechnology enables the development of advanced scaffolds for oral tissue engineering. These nanoscaffolds can mimic the extracellular matrix, providing a supportive environment for cell growth and tissue regeneration. For example, nanofibers and nanocomposites can beused to create scaffolds that support the regeneration of periodontal tissues, bone, or dentalpulp.[15] These materials promote cell adhesion, proliferation, and differentiation, facilitating the repair of damaged oral tissues. Nanotechnology also contributes to regenerative therapiesby enhancing the delivery of growth factors and other bioactive molecules that stimulate tissue repair.[16] Nanoparticles can be designed to release these factors in a controlled manner,improving their bioavailability and efficacy. For instance, nanocarriers can be used to deliver bone morphogenetic proteins (BMPs) or other regenerative agents to accelerate bone healingin dental implants or jaw fractures.[17]

5. Nanotechnology in preventive oral health

Nanotechnology has introduced significant advancements in the prevention of oral diseases through the use of antimicrobial agents. Nanomaterials, such as silver and zinc oxide nanoparticles, are particularly notable for their effectiveness in combating microbial infections in the oral cavity.[18] Silver nanoparticles are well-known for their broad-spectrum antimicrobial properties. They work by releasing silver ions that disrupt bacterial cell membranes and interfere with essential cellular processes. In oral health, silver nanoparticles are incorporated into various dental products, including mouthwashes, toothpastes, and dental materials.[19] Their ability to kill a wide range of bacteria, including antibiotic-resistant strains, makes themeffective in preventing and managing oral infections and reducing the risk of conditions suchas gingivitis and periodontitis. Zinc oxide nanoparticles also exhibit antimicrobial activity, particularly against a range of oral pathogens.[20] They are used in dental products due to theirability to inhibit bacterial growth and biofilm formation.

Additionally, zinc oxide nanoparticles have been shown to have anti-inflammatory properties, which can further contribute to their effectiveness in managing oral infections and promotingoral health.[21] Nanoparticles can enhance the mechanical properties of dental enamel, making it more resistant to demineralization and erosion. For example, nanoparticles of calcium phosphate, such as hydroxyapatite and bioactive glass, are used to remineralize enamel. These nanoparticles can penetrate the microvoids and subsurface lesions of demineralized enamel,facilitating the repair process and restoring its natural hardness. This approach not only helpsin preventing caries but also in managing early carious lesions.[22] Nanotechnology enables thedevelopment of anti-caries agents that can be incorporated into dental care products. For instance, fluoride-releasing nanoparticles can provide a sustained release of fluoride ions, which are essential in preventing dental caries by promoting the remineralization of enamel and inhibiting bacterial activity. Additionally, nanoparticles can be used in varnishes and sealants to protect teeth from carious lesions and erosion.[6,15] Nanoparticles are also employed in products designed to combat dental erosion caused by acidic beverages and foods. Nanocomposites and coatings containing nanoparticles can form a protective layer onthe tooth surface, shielding it from acid attacks and reducing the rate of enamel erosion. Theseproducts help maintain tooth structure and prevent long-term damage.[20]

5.1. Advancements in Diagnostic Imaging and Nanotechnology

Accurate diagnosis is essential in healthcare to prevent false negatives and ensure timely treatment. In vivo imaging offers a non-invasive approach, allowing detection of signs withinlive tissues without surgery. Biological markers have enhanced imaging by detecting cellular-level changes, aiding early disease detection, while nanotechnology has led to high-precisionmolecular imaging agents. These agents are valuable not only in diagnosis but also in monitoring drug distribution and minimizing toxicity by enabling controlled drug release. Established imaging techniques, including X-rays, ultrasounds, CT scans, nuclear medicine, andMRIs, primarily detect tissue-level changes.

However, these techniques have limitations, as traditional contrast agents are fast- metabolizing, non-specific, and sometimes toxic. Nanotechnology addresses these issues withnanomaterials like gold nanoshells, which have low toxicity, high resolution, and adjustable optical resonance, especially beneficial in Optical Coherence Tomography for cancer imaging.Additionally, in situ diagnostic devices, such as capsule endoscopy cameras, can locate internalbleeding and other issues. Future advancements may incorporate nano-sensors in these devices to detect specific chemicals, viruses, and pH levels, enhancing both diagnostic and drug delivery applications.[23,24]

6. Conclusion

The incorporation of nanotechnology into oral medicine signifies a revolutionary advancement that transcends traditional oral health care practices, paving the way for cutting-edge diagnostic methods and enhanced overall oral health. Although the advantages of nanotechnology in this field are considerable, addressing challenges such as regulatory issuesand long-term safety evaluations is essential for its broader implementation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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