Review Article

# Newest Developments of Nanotechnology in Dentistry: A Review of Literature


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## Abstract

**Introduction:** The use of nanotechnology in the field of dentistry has received assiduous attention in recent years. This technology has led to notable advances in materials science and biotechnology. Moreover, the use of nanotechnology has enabled dentists to overcome the limitations of current treatment plans and improve medical services. Several branches of dentistry have benefited from the advancement of this technology. Therefore, the present study aimed to provide readers with various types of nanotechnology used in dentistry, along with their advantages and disadvantages. **Methods**: A query was carried out on PubMed and Google Scholar databases for the articles published from 2000-2022 using the keywords of Nanotechnology, Nanomaterials, Nanocomposites, Nano metals, and Nanorobots. Finally, 83 relevant articles which focused on "Nanotechnology in Dentistry" were selected and explored. **Conclusion**: As evidenced by the obtained results, a combination of nanotechnology and dentistry provides multiple substantial benefits, including aiding in treatment improvement, pain reduction after treatment, cell surgery, more durable dental restorations, and greater patient satisfaction. Therefore, more success and fewer treatment failures are expected in all branches of dentistry with the expanded application of this science.



**Keywords**: Nanotechnology, Nanomaterials, Nanocomposites, Nanometals, Nanorobots

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## Introduction

Nanotechnology is an essential part of the healthcare system, including dentistry. This branch of technology has been effective in various fields of dentistry from diagnosis to prevention and treatment. It encompasses the use of different biological materials which play a prominent role in restoration and cosmetics (1). Among the notable benefits of nano in the field of dentistry, we can refer to ideal dental treatments, improved properties of materials, such as mechanical properties, durability and strength, antimicrobial activity, remineralization, pain control, and prompt recovery of patients using nanotechnology. In other words, this technology has set a new perspective on traditional materials and methods. The assessment of the benefits and effectiveness of this technology in the field of dentistry has revealed that the extensive use of this technology in oral health is promising (2-4).

## Materials Methods

A query on some databases, such as Medline, Cochrane Library, Ui scholarships, and Pubmed Google Scholar was carried out using nano dentistry, nano local-anesthesia, Nanometals, nanoceramics, nano glass ionomers, nanorobots, nanocomposites, and nanotechnology as keywords. A total of 103 articles between 2000 and 2022 containing at least one of the following keywords in their title or abstract were selected and studied. The inclusion criteria entailed the year of publication, the name of the first author, the relevance of the title, and the purpose of the related articles. On the other hand, the exclusion criterion was excessive information. Finally, 83 articles were selected by the researcher for final analysis and review article writing.

## Results

Nanotechnology, also called nanoscience or molecular engineering, is defined as the production of materials and structures in the dimensions of 0.1-100 nanometers (5). This science is used in dentistry to increase efficiency, cosmetics, and finally, patient satisfaction with treatment. For instance, the application of nanoscience in the field of restorative dentistry helps to reduce the negative effects of kinetic reactions and improve the properties of mechanical strength, better performance, beauty, biocompatibility, and ease of work. Nano-based restorative materials also prevent decay (3). The present study assessed several branches of nanotechnology in dentistry, including nanocomposites, nanoceramics, nano glass ionomers, nanoceramics, and nanometals, as well as nanoneedles, nanobots, and nano local anesthesia.

*3.1 Nanocomposite*

Nanotechnology has been used in the case of dental materials as an innovative concept for the development of materials with better properties and anti-decay potential (3). Dental composites are gradually being used as the main choice in restorative dentistry due to the improvement of mechanical properties and apparent resemblance to tooth enamel (6). Every effort has been made to achieve significant improvements in physical properties and overcome such problems as polymerization, shrinkage, coating strength, microhardness, and patient aesthetic satisfaction with dental composites (7).

Nanocomposites and nanocomposite coatings can be described as a combination of two or more materials, including a matrix material and nanoscale secondary particles. The matrix can be a biocompatible polymer, metal, or ceramic. The use of nanotechnology in composite makes it possible to manipulate mechanical properties and create composites more similar to natural teeth (8). Moreover, this technology has facilitated the production of nano-sized filler particles which are added to composite resins either alone or as nanoclusters (9-11).

Nanotechnology allows the production of nano-sized filler particles that are compatible with nano-sized dental composites; therefore, more volume of filler can be added to the composite resin (9). Nanocomposites can be reinforced by the addition of nanofiber-reinforced fillers or E-glass fibers and $TiO_2$ nanoparticles (12). Ion-releasing nanocomposites, such as nano- Dicalcium phosphate anhydrous (DCPA) whiskers or tetracalcium phosphate (TTCP)-whiskers to release Ca and $PO_4$, or calcium fluoride ($CaF_2$) nanoparticles to release fluoride can also be used to increase mineral content (13,14). Some of these ion-releasing nanocomposites, including polymer-kaolinite nanocomposites which release fluoride, may be suitable materials for decay prevention (15).

Nanocomposites reduce shrinkage and failure in polymerization in terms of cosmetics and strength by increasing filler volume and decreasing the resin matrix. They are able to release fluoride, phosphate, and calcium ions to increase fluorapatite and prevent decay with well-formulated mechanical properties. These composites with high strength and ion-releasing properties can be effective in the reduction of secondary caries and restorative fractures, which are two common problems in restorative dentistry (13).

Filtek Supreme was the first dental nanocomposite used in 2002. This restorative material displays good modeling properties both for anterior and posterior teeth, can easily be adapted, has low levels of stickiness, offers excellent handling properties, and has outstanding polishability (16). The enrichment of resin nanocomposites with reinforced fillers and $CaPO_4$ nanoparticles can facilitate remineralization without losing mechanical properties. The dental composite containing nanoparticles of amorphous calcium phosphate (NACP) and glass particles may demonstrate a fourfold increase in enamel remineralizability, compared to fluoride-releasing composites since ion-releasing nanocomposites lead to remineralization, while glass particles increase composite strength (3).

Other research groups have reported that composites containing nanofillers at higher concentrations have better mechanical properties. Nonetheless, it seems that the improvement of mechanical properties is up to the maximum desired percentage of nanofillers in nanocomposites, and no improvement is observed after that. The additional amount of nanofillers is beneficial to the enhancement of the physical and mechanical properties of composite resins; consequently, the achievement of the highest possible percentage of filler is the ultimate goal. However, the maximum amount of filler must be carefully considered due to the existing limitations (16).

Some recent studies have referred to nanocomposite dentures in which inorganic fillers are homogeneously distributed in the nanoscale. Based on experiments, nanocomposites in dentures are more durable and show higher abrasion resistance, as compared to acrylic teeth and dental microfiber composites. Moreover, composite resins containing nanofillers in dentures are superior in terms of color (17).

*3.2 Nano-glass ionomers*

Glass ionomers with nanoparticles are called nano ionomers. The chemical bonding of glass ionomers to teeth leads to their widespread use in dentistry. Nano ionomers have fluoride-releasing properties and are aesthetically pleasing. They have higher optical and translucency properties than conventional glass ionomer cement (18). In their study, Decalo et al. reported that the addition of nano-sized particles to conventional glass ionomers increased its compressive strength and elastic modulus. It was also effective in reducing the time of placement and stabilization (19).

Nano glass ionomers are more compatible with hard tooth tissue, in comparison with conventional glass ionomers. They show a statistically lower degree of microleakage, compared to glass ionomer resins, in both occlusal and gingival restorations (20). It has been observed that chitosan nanoparticles, the ductile form of chitin, a polysaccharide in crustacean shells, are effective in improving the flexural strength of glass ionomers due to the increased reaction between glass ionomer matrix and chitosan filament (21).

The use of bioactive nature, hydroxyapatite, and fluorapatite are included in the resin structure of composites and glass ionomers. In fact, the addition of nanohydroxyapatite and nano fluorapatite to glass ionomers significantly improves their flexural, tensile, and compressive strength. Compared to nano-hydroxyapatite-modified glass ionomer, nano fluorapatite-modified glass ionomer has higher crystallization properties, leading to better mechanical properties. Another benefit of adding nano apatite is the increased bond strength between the tooth and glass ionomer. This conclusion stems from two observations, one of which is the similarity between tooth apatite and glass ionomer nano apatite, which enhances ionic reactions between teeth and glass ionomer. Moreover, the smaller size of nano apatite crystals facilitates penetration into dentin tubules and enamel pores (22).

*3.3 Nano-ceramics*

Nanoceramics are another product of nanotechnology (23). Nanophase ceramics can be assigned to three categories based on structural characteristics: Nanoparticles, Nano scaffold, and Nanoclays (24).

3.3.1 Ceramic nanoparticles: These nanoparticles are made of inorganic materials (ceramic). They contain some particles, including silica, titania, and alumina (25), which protect enclosed molecules, such as proteins, enzymes, and drugs, from the deforming effects of external pH and temperature; however, despite changes in pH, swelling and porosity changes do not occur (26).

*3.3.2 Scaffold ceramics*

A scaffold refers to a structure that allows cells and extracellular matrix to interact and provide mechanical support for cell and tissue growth. This scaffold can be of two types: high porosity (pore size 50 nm) and low porosity (pore size 10 nm). Ceramic nano-scaffolds have high porosity, high area and structural stability, and longer degradation time (26).

*3.3.3 Ceramic nano cells*

Their structure is similar to thin layers, and each layer has a thickness of several nanometers and a length of several hundred to several thousand nanometers (27). Nanoparticles show great potential for application in polymer and ceramic structures due to the reduction of sediment and catalytic failure processes (28). Ceramic nanoparticles are mostly composed of oxides, nitrides, or carbides and are mainly used as coatings to resist temperature and chemical effects (27). Nanoceramic composites are also made using both nanotechnology and ormocer technology, which include modified methacrylate, silicon dioxide-containing nanofillers, and a matrix filled with polysiloxane-modified methacrylate particles, which replaces the resin matrix (29).

The application of nanotechnology to nanoceramics requires consideration of other properties of ceramics, such as electronic, biological, optical, and insulation, apart from its main properties, including hardness, rigidity, temperature resistance, and corrosion (30). Nanoceramics convey unique and useful properties to dental materials, and we will witness dramatic changes in dentistry in near future (31).

*3.4 Nano-metals*

The use of nanometals in dentistry ranges from diagnosis to prevention and therapeutic purposes. They improve mechanical properties and transfer antimicrobial activity to other materials. The most common nanometals used in dentistry include Ag, Ti, Cu, Au, Zn, and Zr. Gold and silver are mostly used in pure form and the rest in the form of nan oxide. They are used in resin composites, resin-based acrylic dentures, endodontics, dental implants, restorative cement, and orthodontic brackets (1). The following are some examples of the use of nanometal particles:

*3.4.1 Restorative materials*

Materials used in restorative dentistry, such as resin composites with good cosmetic properties, often fail in treatment due to biofilm accumulation, secondary caries, and bulk fractures (32,33). In the same vein, the use of inadequate tools and microleakage in the root canal will lead to the failure of the healing process (34). Moreover, Ag, ZnO, and Zr nanoparticles are added to composite resins, cavity varnishes, glass ionomer cement, in-channel drugs (such as calcium hydroxides and sealers) to overcome these problems (1,35-56).

*3.4.2 Prosthetic materials and dental implants*

Acrylic particles, complete dentures, or implants usually provide complete oral rehabilitation for missing teeth. Dentures are made of polymethyl methacrylate resin, which has a rough inner surface and accumulates biofilms (57). To overcome such problems as Candida colonization which causes stomatitis (inflammation of the oral mucosa and gums) due to dentures or failure of implant treatment, Ag, $ZrO_2$, and $TiO_2$ nanoparticles are added to polymethyl methacrylate or as a cover shape to the occlusal surface of the implant. They promote mechanical and antimicrobial properties (58-61).

3.4.3 Orthodontic devices

In the most complex orthodontic treatments, orthodontic brackets act as plaque retainers and cause the formation and proliferation of biofilms, proliferation of various bacteria, reduction of pH, and demineralization of enamel (62). The addition of Cu and Zn nanoparticles to orthodontic brackets inhibits plaque biofilm and has an anti-decay effect. Moreover, this method increases biofilm formation and prolongs the healing process with a repeated detachment of brackets (63).

Nanometals and their oxides are widely used in dentistry due to their desirable mechanical, antimicrobial, and regenerative properties. Nevertheless, their potential benefits often come with the risk of nanoscale-sized toxicity and reactivity; therefore, great caution should be exercised in their application in dental materials (64).

3.5 Nanorobots

With the advancement of technology, nanorobots have also been used in dentistry. These small work systems are used in such cases as the destruction of cariogenic bacteria, the reconstruction of dental defects caused by caries, and the assistance of examining, altering, or interrupting nerve impulses (65). Nano-robots increase accuracy and improve dental processes. They are designed in dimensions of 1-10 nanometers with a diameter of 0.5-3 microns. Due to their small size, they can be easily absorbed by blood or through body canals and can be guided by dentists using acoustic and electromagnetic waves (66,67).

Nanorobots can also help resolve the problem of dentin allergies, eliminating this sensitivity in just a few minutes by closing open dental tubules (67). Moreover, nanorobots can clear the oral cavity of caries and prevent bad breath by the identification of pathogenic bacteria. This latter type of nanorobots is typically made of nano-sized hydroxyapatite molecules which are used in toothpaste and mouthwashes and are inactivated if accidentally swallowed (68,69).

*3.6 Nano local anesthetics*

Nowadays, this group of anesthetics has received assiduous attention due to their applications. In addition to prolonging the anesthesia time, liposomal formulations in the nano-anesthesia group help better control pain and speed up patients' recovery. Meanwhile, bupivacaine is used by liposomal spheres in other cases, such as joint surgeries. liposomal spheres containing lidocaine or a variety of ropivacaine can also be used as a local anesthetic at the injection site (4).

Nano-scale drug delivery systems have many advantages over larger systems. Nanosystems include the liposomal technique. Compared to other methods, this technique has greater biocompatibility and survival, as well as good coordination with the biological environment of nanostructures (70). Alternatively, a combination of lidocaine and prilocaine is employed to make nano-hydrogels using nanostructured capsules. These capsules have been utilized with carbopol hydrogel as a local anesthetic in the mouth (71).

*3.7 Nano needles*

Stainless steel crystals are designed to produce nano-sized suture needles which perform periodontal surgery on a very small scale (72). With the advancement of technology, it is possible to make nano pliers, and in the near future, cell-scale surgery in the oral environment will be possible with the help of these nano-forceps and nano-needles (73).

*3.8 Nanorobots in orthodontics*

The orthodontic specialty is moving towards a new era based on nanorobotics medicine. The use of nanorobots to accelerate tooth movement in animal studies through the use of nanoelectromechanical systems was observed in the present study (74). Another research demonstrated that special brackets created by robots are more effective in treatment, as compared to conventional bracket systems. Moreover, the position of bracket installation which is improved in robotic brackets has a significant impact on the progress of orthodontic treatment due to its time perseverance and increased efficacy (75).

*3.9 Nanorobots in diagnosis*

The combination of nanomaterial science and biology has led to the development of diagnostic devices, analytical instruments, and drug-carrying devices in the body. Nano diagnostic science uses biosensor technology, one of the most promising and intensive systems which analyze biological diagnostic elements, such as DNA and proteins (76). For instance, a related study had pointed to the use of gold nanoparticles to analyze salivary chemical changes in patients with oral cancer (77). In another study, nanotechnology scientists successfully produced microchips coated with biological molecules. This chip is designed to emit an electrical signal when molecules detect disease symptoms (76).

*3.10 Nanoparticles in imaging*

Various imaging techniques, such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), are currently applied in dentistry; moreover, nanoparticles have been recently introduced, bringing about dramatic changes to CT and MRI imaging. For instance, in the MRI technique, nanoparticles increase the spatial resolution, make better contrast of soft tissues, and create advanced and differential choices for metabolic structures. Nevertheless, nanoparticles may cause some adverse effects, including less sensitivity to contrast agents. Nanoparticles used in CT can improve resolution, infinite penetration depth, and make better contrast of soft tissues upon the introduction of contrast agents. However, the use of nanoparticles can cause inadequate contrast of soft tissues without the injection of contrast agents and less sensitivity to contrast agents (78).

*3.11 Nano impressions*

The field of dental materials has evolved with the advent of nanotechnology research which focuses on the production and application of nanoparticles with high-quality structural properties (79). Nanofillers combined with vinyl polysiloxanes lead to better flow molding materials, improved hydrophilic properties, and reduced voids for subsequent steps. These materials also aid in the increased production of surface details and provide a molding material with better properties (80).

3.12 Nanotechnology in bone tissue engineering

Nanotechnology represents a prime frontier with an ability to noticeably develop the sector of bone tissue engineering. Current obstacles in regenerative techniques encompass impaired cell proliferation and differentiation, inadequate mechanical electricity of scaffolds, and insufficient manufacturing of extrinsic elements important for sufficient osteogenesis which are prominently overcome by nanotechnology. More promising therapeutic outcomes in patients with large bone deficits and osteo degenerative diseases are expected with ongoing advances in nanotechnology (81).

*3.13 Nanotechnology in endodontics*

The emergence of nanotechnology exerted a profound impact on endodontic therapy. Nanotechnology can be utilized in fillers, irrigants, and photodynamic therapy to achieve more beneficial results (82). Furthermore, nanoscience can be used in order to make root repair materials (83). Based on the reviewed studies, antibacterial nanoparticles can be used for disinfection and have displayed acceptable efficacy in the elimination of bacterial cells. Moreover, nanotechnology is applicable to sealers used in endodontics, and nano-sized materials can enhance the anti-leakage property of these sealers. Therefore, nanotechnology can improve the success rate of endodontic therapies (82).

## Discussion

With the great advancement of nanotechnology, all branches of dentistry have also benefited from its desirable changes. Today, the integration of these two sciences has increased patient satisfaction, the durability of treatments performed over time, and the use of the advances made in various fields related to dentistry, especially the nanomaterials sector. The reduction of the aggressiveness of treatments, which has always been a matter of concern to dentists, is also addressed. Therefore, the application of nanotechnology in dentistry can be considered a major contributing factor to the reduced length of treatment processes, improved quality of services, and reduced unwanted complications.

## Conflict of Interest

The authors claim that there was no conflict of interest in this study.

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The authors have no commercial relationships to declare.

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