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THE IMPACT OF NANOTECHNOLOGY AND INNOVATIONS IN DENTISTRY

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ABSTRACT
Nanotechnology has expanded rapidly into all areas of medicine and dentistry and offers new ways of solving medical and dental problems. In dentistry, nanotechnology has been used to develop a variety of dental materials, with notable success. This narrative review discusses applications of nanotechnology in dentistry that could enhance the longevity and prognosis of dental treatment. It focuses on dentin hypersensitivity, caries prevention, conservative dentistry, endodontic treatment, photodynamic therapy, prosthodontics, periodontics, implantology and regenerative dentistry, orthodontic treatment and the management of oral cancer, and it also considers nanotoxicity. Recent advances in nanotechnology hold promise for a significant shift in the field of dentistry.

KEYWORDS: Nanotechnology, Regenerative dentistry, Conservative dentistry, Photodynamic therapy, Oral cancer

1. INTRODUCTION
The field of nanotechnology has evolved considerably over the last few decades. Progress in nanotechnology has led nanoparticles (NPs) to be regarded as among the most promising biocompatible materials in medicine and dentistry (Guruswamy Pandian et al., 2026; Marciano et al., 2026; Natoli et al., 2026). Nanotechnology deals with the development of materials, devices or other structures with at least one dimension of 1 to 100 nanometers (Figure 1), which are known as nanomaterials (El-Morsy et al., 2025; Farjaminejad et al., 2026; Wu et al., 2026; Xu et al., 2026).



Figure 1. Macroscale vs. microscale vs. nanoscale.

2. Nanoparticles / Nanostructures / Nanomaterials
New materials come with new properties, which create new opportunities for technology. Two principal factors cause the properties of nanomaterials to differ from those of bulk materials: the increase in relative surface area and quantum effects. Current research focuses on a wide array of nanoscale structures (nanostructures). Nanostructures have applications in many areas of life, including industry, communications, science, medicine (nanomedicine) and dentistry (nano-dentistry). Nanoparticles can be classified in several ways, as presented in Figure 2 (Kumar and Sinha, 2018; Bayda et al., 2020; El-Morsy et al., 2025; Wu et al., 2026).

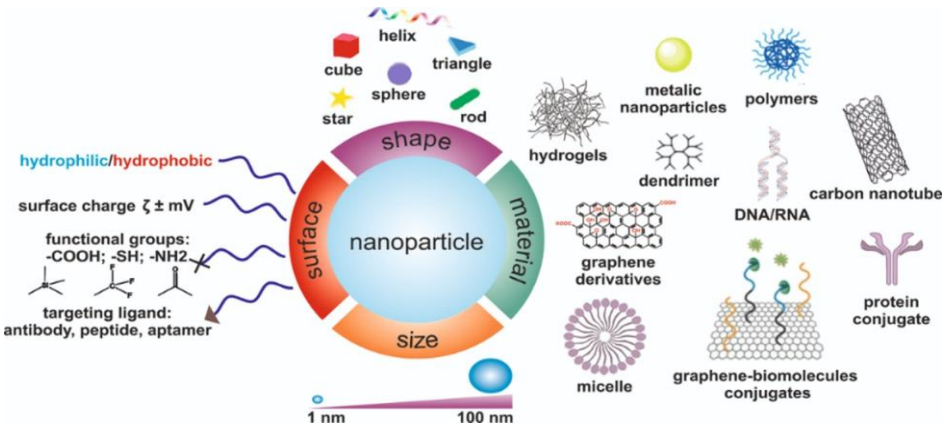
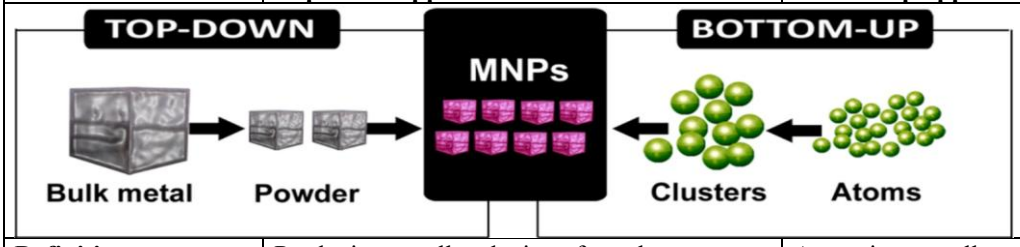


Figure 2. Different types of nanoparticles.

3. Approaches of Nanotechnology

Based on application, use and technology, there are four approaches to nanotechnology. Two of them, the top-down and bottom-up approaches, are used in the market and are compared in Table 1. The other two are still at the experimental level: the functional approach, which seeks to develop components with a desired functionality without regard to how they might be assembled, and the biomimetic approach, which seeks to apply biomolecules in nanotechnology applications (Kumar and Sinha, 2018; Marciano et al., 2026).

Table 1. Differences between the top-down and bottom-up approaches.

	Top-down approach	Bottom-up approach
		
Definition	Producing smaller devices from larger ones while achieving precision in structure and assembly. Example: NEMS (Nanoelectromechanical systems) which are used in cancer treatment.	Arranging smaller components into more complex assemblies, in which the covalent bonds are extremely strong.
Advantages	Large scale production: deposition over a large substrate is possible. Chemical purification is not required.	Ultra-fine nanoparticles, nanoshells, nanotubes can be prepared. Deposition parameters can be controlled. Narrow size distribution is possible (1-20 nm). Cheaper technique.
Disadvantages	Broad size distribution (10-1000 nm). Varied particle shapes or geometry. Difficult control over deposition parameters. Expensive technique.	Large scale production is difficult. Chemical purification of nanoparticles is required.
Dental applications	Nano-composites. Nano-impression materials. Nano-solutions. Nano-encapsulation. Nano-needles. Bone substitutes. Implants. Surface disinfectant. Decay-resistant tooth. Salivary diagnostics. Glass ionomer cement.	Inducing anesthesia. Major tooth repair. Dentin hypersensitivity. Dental durability and cosmetics. Nanorobotic dentifrices. Local drug delivery. Nano diagnostics (Photosensitizers and carriers). Therapeutic aid in oral diseases. Orthodontic treatment. Bionic mandible.

NEMS, nanoelectromechanical systems.

4. Nano-dentistry

Nano-dentistry is still considered an emerging field with great potential to yield a new generation of technologically advanced biomaterials and biotechnology, including tissue engineering, nano-diagnostics and, ultimately, dental nanorobotics, in prosthodontics, orthodontics, periodontics and operative or restorative dentistry (Figure 3; El-Morsy et al., 2025; Farjaminejad et al., 2026; Guruswamy Pandian et al., 2026; Marciano et al., 2026; Natoli et al., 2026; Wu et al., 2026; Xu et al., 2026).

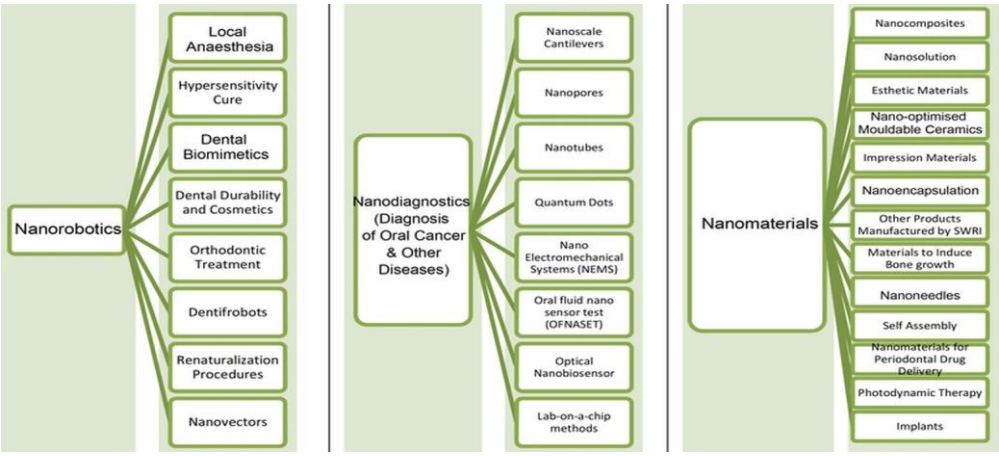


Figure 3. Nano-dentistry.

5. Applications and Advancements of Nanotechnology in Dentistry

5.1 Nanotechnology in Dentin Hypersensitivity

Dentin hypersensitivity may be caused by changes in pressure transmitted hydrodynamically to the pulp. Hypersensitive teeth have been reported to have eight times the surface density of dentinal tubules, and tubules twice as wide in diameter, as nonsensitive teeth. Dental nanorobots have been proposed that could precisely occlude selected tubules within minutes, offering a quick and lasting cure (Amaechi et al., 2018; Marciano et al., 2026).

5.2 Role of Nanoparticles in Dentin Stabilization

Dentinal collagen stabilization has been explored to improve resistance to degradation, to improve bond strength in adhesive restorations, to manage dentinal hypersensitivity and to stabilize the surface dentin of root canal walls. Dentin stabilization is achieved by cross-linking the dentin collagen, which improves its stability. Nanoparticles of bioactive polymers such as chitosan have been shown to enhance the mechanical properties of dentin collagen, reinforce collagen scaffolds and create a more suitable biomimetic environment for cells. Chitosan is a non-toxic, biocompatible polymer, which allows its widespread use in biomedical applications. Nanoparticle-conjugated photosensitizers, such as Rose Bengal-conjugated chitosan nanoparticles, could be activated with green light (540 nm) to stabilize dentin collagen (Amaechi et al., 2018).

5.3 Nanotechnology for Preventing Dental Caries

Researchers developed a nano-toothbrush by incorporating nanogold or nanosilver colloidal particles between the toothbrush bristles. Silver nanoparticles, zinc oxide nanoparticles and quaternary ammonium polyethylenimine have a bactericidal effect against a large number of bacterial species, including Streptococcus mutans and Lactobacillus spp. Toothpastes containing calcium carbonate nanoparticles and 3% nanosized sodium trimetaphosphate have also been reported to promote remineralization of early carious lesions. Toothpastes containing nano-hydroxyapatite crystals significantly increased microhardness values in human enamel after an erosive challenge (Kavoosi et al., 2018).

In 2020, Sadony et al. conducted a study to evaluate the antimicrobial efficacy of silver nanoparticles (AgNPs) and gold nanoparticles (AuNPs), with and without a 970 nm diode laser, for dentin disinfection. The greatest reduction in bacteria was found in the group combining AgNPs with the diode laser (Sadony and Abozaid, 2020).

Nanorobotic dentifrices (dentifrobots) are envisaged as devices 1-10 microns in size that crawl at 1-10 microns per second and could be delivered by mouthwash or toothpaste to cover supragingival and subgingival surfaces, metabolizing trapped organic matter into harmless and odorless vapors and performing continuous calculus debridement (Figure 4).

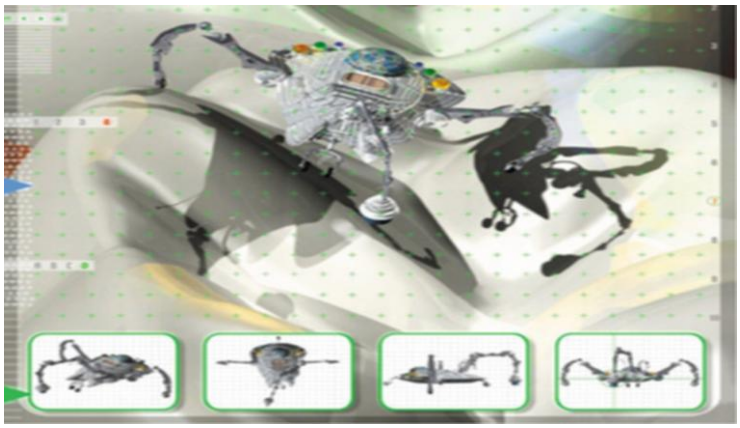


Figure 4. A nanorobot performing a dental restorative procedure on the occlusal surface of a molar, shown as an aid to visualization. Cover illustration by Peter S. Solarz, originally published on the cover of the November 2000 issue of the Journal of the American Dental Association (© American Dental Association).

5.4 Nanotechnology in Conservative Dentistry

5.4.1 Nanotechnology in Local Anesthesia

Nanorobots and nanoterminators are proposed as new advances in local anesthesia, with fewer side effects and complications. In nano-dentistry, a suspension containing millions of active analgesic dental robots is envisaged to be instilled on the patient's gingiva, resulting in anesthesia (Moradkhani et al., 2018).

5.4.2 Nanocomposites

Nanocomposites are resin composites containing filler particles smaller than 100 nm. They offer superior hardness, polishability, smoothness, precision of shade characterization, flexural strength, modulus of elasticity and translucency, as well as excellent handling properties, a reported 50% reduction in filling shrinkage and unique physical, mechanical and optical characteristics. Nanocomposite systems have the potential to improve the continuity between the tooth structure and the nanosized filler particles and to provide a more stable and natural interface between the mineralized hard tissues of the tooth and these advanced restorative biomaterials (Figure 5; Chole et al., 2017; Moradkhani et al., 2018; El-Morsy et al., 2025).

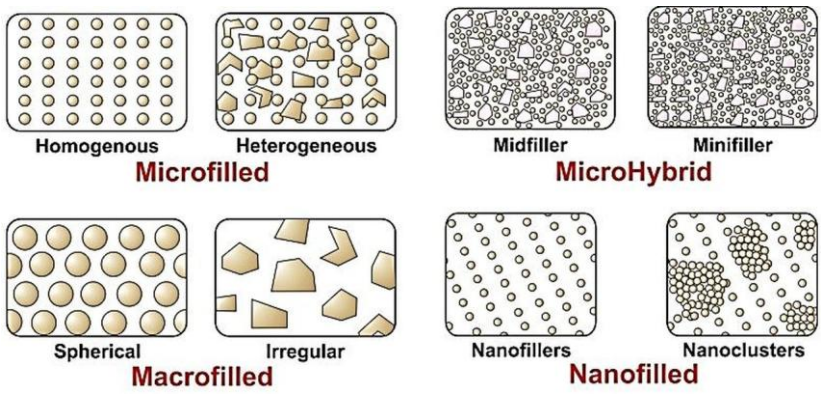


Figure 5. Different types of composite particles.

5.4.3 Nanotechnology in Glass Ionomer Cement

Incorporating nano-hydroxyapatite and nano-fluorapatite crystals, 100-200 nm in size, into glass ionomer cement (GIC) improves its physical, chemical and mechanical properties and the setting reaction, improves polysalt bridge formation, bonds better with dentin, gives greater compressive strength, increases resistance to biomechanical degradation and increases surface roughness. However, the amount of fluoride released is the same as that of conventional resin-modified GIC (AlOtaibi, 2019).

5.4.4 Nanoparticles in Adhesive Dentistry

Nanosolutions produce unique, dispersible nanoparticles that can be used in bonding agents, ensuring homogeneity so that the adhesive is perfectly mixed every time. Such adhesives may contain nanoparticles such as nano-silver (nAg), nano-amorphous calcium phosphate (nACP), nano-hydroxyapatite (nHA), titanium dioxide (TiO_2), nano-quaternary ammonium dimethacrylate (nQADM), zinc oxide (ZnO) and magnesium oxide (MgO). All of them improve the bond strength between the restorative material and the tooth structure. nHA is helpful for occluding dentinal tubules, although it decreases compressive strength. nAg, nQADM and TiO_2 act as antibacterial agents without altering the physical properties, and TiO_2 nanoparticles also have a positive effect on tooth remineralization. The incorporation of nanocapsules loaded with core materials as a major ingredient of self-healing bonding resin has been reported by Ouyang and co-workers. Nanoencapsulated monomers in dental adhesives have also been shown to enhance bond strength (Kumar and Sinha, 2018; El-Morsy et al., 2025; Marciano et al., 2026).

5.5 Nanotechnology in Dental Durability and Cosmetics

Durability can be achieved by enhancing the properties of restorative materials and by increasing pH and bactericidal ability to prevent the formation of secondary caries. Nanofillers provide higher wear resistance, a smooth, high-luster finish that is retained over time and better stain resistance. Durability and renaturalization can be improved by replacing the upper enamel layers with pure sapphire and diamond and by using a rechargeable nano-amorphous calcium phosphate (nACP)-filled composite resin, a "smart" material as described by researchers, which can rapidly neutralize bacterial acids released along the restoration/tooth margins and thereby inhibit the initiation of secondary caries. nACP is present in composites, luting cements and bonding agents. The application of a nanocomposite coating with lactose-modified chitosan and silver nanoparticles, and the addition of cross-linked quaternized polyethyleneimine nanoparticles, were reported to have a long-lasting, stable antibacterial effect without leaching into the surrounding environment. Tooth-whitening agents have been nano-modified, for example with calcium peroxide nanoparticles, to increase their whitening efficiency and minimize harmful side effects. Coating agents and ultrafine polishing protect tooth surfaces against damage caused by cariogenic bacteria, because bacteria can be removed easily, leading to less staining and better esthetics (Guruswamy Pandian et al., 2026; Marciano et al., 2026; Natoli et al., 2026; Xu et al., 2026).

5.6 Nanotechnology in Endodontic Treatment

5.6.1 Nanotechnology in Endodontic Instruments

Nanomaterials have been suggested for the surface modification of rotary nickel-titanium (NiTi) files to reduce the incidence of failure. The mechanical properties of instruments used in endodontic procedures can be evaluated by nano-

indentation testing to investigate the impact of cyclic fatigue on NiTi files, to assess the hardness of endodontic instruments and to evaluate the failure mechanisms of NiTi instruments (Farjaminejad et al., 2026; Marciano et al., 2026).

5.6.2 Nanobased Irrigants

Nanoparticles can disperse rapidly into the hard-to-reach spaces of the complex root canal system, which leads to a better antimicrobial effect. Nanoparticles such as chitosan, zinc oxide, magnesium oxide (MgO) and silver nanoparticles can disrupt the bacterial cell wall and disintegrate biofilms in the root canal system. Another important introduction in endodontics is bioactive glass for root canal disinfection, which maintains an alkaline environment over time and thus has an antimicrobial effect. The cytotoxic impact of silver nanoparticles as an irrigant was investigated by the National Institutes of Health, and nano-silver was observed to have the same effect as sodium hypochlorite (NaOCl) on Enterococcus faecalis and Staphylococcus aureus, while nano-MgO at a concentration of 5 mg/L showed long-term efficacy in removing E. faecalis in comparison with 5.25% NaOCl (Kavoosi et al., 2018).

5.6.3 Photodynamic Therapy (PDT) with Nano-photosensitizers and Carriers

Nanoparticle-based photosensitizers can augment the antimicrobial and anti-biofilm effects of photodynamic therapy. Nanoparticles encapsulating photoactive drugs could be a favorable supplement in antimicrobial endodontic therapy. Nanoparticles can also act as carriers for photosensitizers, as in the case of quantum dots.

Saafan et al. (2018) conducted a study to assess the antibacterial efficacy of a 650 nm diode laser, methylene blue (MB) and silver nanoparticles (AgNPs) against Streptococcus mutans. The combination of laser, MB and AgNPs as photosensitizers produced the greatest reduction in bacteria (Saafan et al., 2018).

5.6.4 Nanomaterials in Endodontics

After canal disinfection, achieving a “hermetic seal” is a major goal of root canal treatment. The incorporation of nanoparticles into obturating materials enhances their sealing properties and antimicrobial efficacy; for example, chitosan has broad antimicrobial, antiviral and antifungal activity, biocompatibility and biodegradability. Improvement in the quality of cements used as fillers has been reported with calcium-enriched mixture (CEM), mineral trioxide aggregate (MTA), calcium phosphate hydroxyapatite and nano-hydroxyapatite-chitosan. CEM and nano-hydroxyapatite-chitosan were found to have more appropriate bioactive features based on pH values. Nanoparticles in sealers can also prevent leakage in root canal therapy: adding bismuth oxide nanoparticles, nano zinc oxide or tricalcium silicate-based cements improves push-out and compressive strength without any significant impact on radiopacity. A nano-hydroxyapatite-filled epoxy resin sealer provided an appropriate apical seal against dye, enhanced mechanical properties and decreased the setting time of endodontic materials. Adding silica nanoparticles to MTA resulted in a faster setting time without any unfavorable influence. Embedding gutta-percha (GP) with nanodiamonds (GPND) enhanced the mechanical properties of GP. Bioceramics for retrofilling and repair materials are other applications of nanotechnology in endodontic treatment (Moradkhani et al., 2018; Farjaminejad et al., 2026; Marciano et al., 2026).

5.6.5 Advances of Nanotechnology in Endodontics

Current treatment modalities offer high levels of success, yet an ideal therapy might consist of regenerative approaches in which diseased or necrotic pulp tissue is removed and replaced with healthy pulp tissue. Fioretti et al. showed that α-MSH (a melanocortin peptide) possesses anti-inflammatory properties and also promotes the proliferation of pulpal fibroblasts, and they reported α-MSH as a new active biomaterial for endodontic regeneration (Figure 6; Farjaminejad et al., 2026; Natoli et al., 2026; Wu et al., 2026).

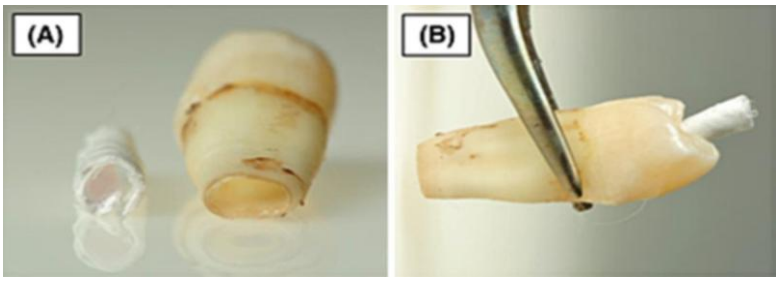


Figure 6. Illustration of how an electrospun tube can be inserted in the canal for regenerative endodontics. (a, b) Transverse and lateral views of an extracted premolar with a tubular electrospun scaffold.

5.7 Nanotechnology in Prosthodontics

5.7.1 Nanotechnology in Denture Base Materials and Liners

Nano-sized fillers have been used in denture base materials because of their superior dispersion properties, low aggregation potential and biocompatibility with the organic polymer. Incorporating TiO_2 nanoparticles into a poly(methyl methacrylate) denture base improves its antibacterial and mechanical properties, and adding zirconium oxide nanoparticles improves hardness, flexural strength and fracture toughness, as well as the transverse strength of a repaired denture base. Nano-modified chlorhexidine coatings used on denture soft liners and obturators inhibit fungal infections without affecting the hydrophilicity and water uptake of denture silicones, and also release soluble chlorhexidine into the saliva (Calisir, 2019; Sahithi et al., 2019).

5.7.2 Nano-filled Composite Denture Teeth

Nanocomposite denture teeth, made of poly(methyl methacrylate) with nano-sized filler particles, are highly polishable and stain resistant, have a lively surface structure and offer superior surface hardness and wear resistance.

Improvements have also been observed in resin nano-ceramic computer-aided design and computer-aided manufacturing (CAD/CAM) blocks, which show superior esthetics, durability and fracture resistance and can be easily modified and customized after milling. However, further research is required to ensure safety by addressing their long-term biocompatibility, toxicity, and mechanical and physical properties (Moradkhani et al., 2018; Sahithi et al., 2019).

5.7.3 Nanotechnology in Impression Materials

Nano-fillers or nano-silica are used with vinyl polysiloxanes to produce a unique variety of siloxane impression materials. These materials have better flow, especially when pressure is applied, improved hydrophilic properties and enhanced detail precision (Tahmasbi et al., 2019).

5.8 Nanotechnology in Periodontics

Nanotechnology has also been adapted for drug delivery in the treatment of periodontal diseases, for example through tetracycline-loaded nanoparticles, which release the loaded drug gradually and so prolong contact with the diseased site. Niosomes are stable, non-ionic vesicles that offer controlled drug delivery with penetration through biological tissue. Fullerenes are hollow carbon molecules that come in different shapes and have been used for other purposes, such as radical scavenging and as antioxidants; they have also been studied for many potential applications, including drug delivery (Natoli et al., 2026; Xu et al., 2026).

5.9 Nanotechnology in Implantology and Regenerative Dentistry

Nanotechnology can be used in tissue repair and replacement, implant coatings, tissue regeneration scaffolds, structural implant materials, bone repair, bioresorbable materials and smart implantable materials. With regard to tissue regeneration, nanomaterials have excellent physicochemical properties and biomimetic features that enhance cell growth and deliver therapeutic agents. Nanomaterials can overcome problems encountered with the current scaffolds used for bone regeneration: nanotubes and nanoparticles enhance the chemical and mechanical features of the scaffold and increase cell migration, proliferation and tissue regeneration. Nanofibers provide an ideal environment for cell migration because of their similarity to the extracellular matrix and their high porosity (Calisir, 2019; Sahithi et al., 2019; Izadi et al., 2020).

5.10 Nanotechnology in Tooth Repair

Nanorobotic manufacture and installation of a biologically autologous whole replacement tooth, including both mineral and cellular components, is predicted to become feasible with the use of an affordable desktop manufacturing facility that would fabricate the new tooth in the dentist's office (complete dentition replacement therapy). Chen et al. took advantage of recent developments in nanotechnology to simulate the natural biomineralization process and create dental enamel, using highly organized micro-architectural units of nano rod-like calcium hydroxyapatite (HA) crystals arranged roughly parallel to each other (Sahithi et al., 2019).

5.11 Nanotechnology in Orthodontic Treatment

Applications of nanotechnology in orthodontics are still largely speculative, yet the future looks promising for nano-designed orthodontic bonding materials, nanovectors for gene delivery to stimulate mandibular growth, and nanomechanical sensors. Orthodontic nanorobots are envisaged to manipulate the periodontal tissues directly, delivering rapid and painless tooth straightening, rotation and vertical repositioning within minutes to hours instead of weeks or months. Nanoparticles have also recently been used as a component of dry lubricants (Tahmasbi et al., 2019).

5.12 Nanotechnology in the Management of Oral Cancer

Prevention is the best cure for cancer, and early detection greatly increases survival rates. To improve medical diagnostics and bioreceptor performance, nano-bioreceptors and nano-biosensing were introduced. Nano-biosensors can detect cancer cell molecules at very early stages and at very low concentrations because their nano size increases the sensitivity and response time of the biosensor. This not only enhances the performance of biosensors but also makes them more feasible and less costly to manufacture. Nanoparticles (NPs), such as dendrimers, fullerenes and inorganic NPs, are also suitable for drug and gene delivery, probing DNA structures and other uses. In some studies, NPs have been used as tumor biomarkers (He and Alexandridis, 2017; Sohal et al., 2018).

5.13 Nanoneedles, Nanotweezers and Nanoencapsulation

Nano suture needles incorporating nano-sized stainless steel crystals have been developed. Nanotweezers are also under development and are expected to make cell surgery possible in the near future. Nanoneedles for delivering local anesthetics for surface anesthesia, nanotips for scaling, and nanoencapsulations, including novel vaccines, antibiotics and drug delivery systems with reduced side effects, are also being developed (Figure 7; Prausnitz, 2015).

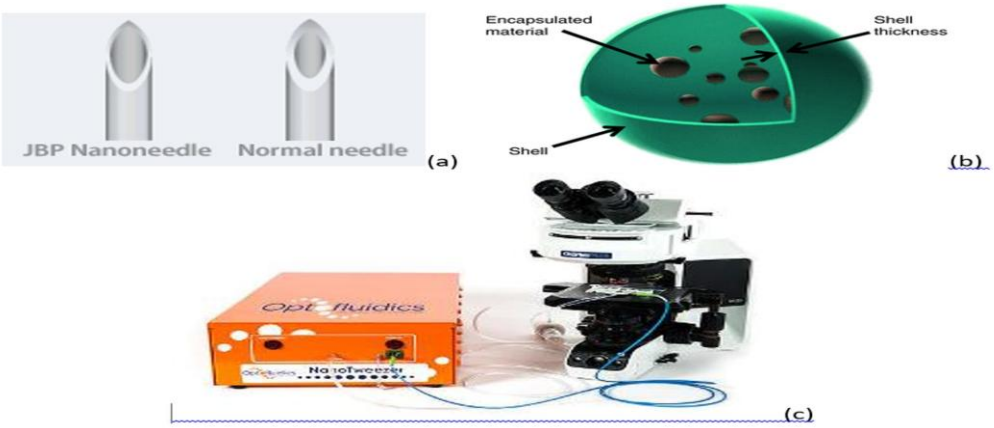


Figure 7. (a) Nanoneedles vs. normal needles; (b) nanoencapsulation; (c) nanotweezers.

6. Nanotechnology and Lasers

Nanotechnology meets laser technology in photodynamic therapy (PDT), in which nanomaterials act as photosensitizers or carriers that interact in the presence of laser or light. PDT has many dental applications: as an antibacterial in periodontal diseases, endodontic disinfection and caries prevention, as an antifungal, and for the diagnosis and treatment of cancer. Nanotechnology and light also meet during the curing of nanofilled, reinforced resin restorative materials, which gives the restoration better physical properties and a bactericidal effect (Tomsia et al., 2013; Saafan et al., 2018; Albu et al., 2026).

7. Nanotoxicity

"Nanotoxicity" describes toxicity arising from nanoparticles whose behavior cannot be predicted from the properties of the same material in bulk chemical form. Toxicity may also arise from other substances present in the nanomaterial. Those at higher risk of exposure to dental nanomaterials are production-site workers, research and development staff, dental staff and patients. In the clinic, most dental nanomaterials are applied directly in the oral cavity, which may allow them to enter the bloodstream readily through absorption across the oral mucosa or through the digestive tract (Razumova et al., 2025; Hromcik et al., 2026).

8. CONCLUSIONS

Nanotechnology is expected to alter health care fundamentally by providing novel methods for disease diagnosis and prevention, therapeutic selection tailored to the patient's profile, drug delivery and gene therapy. It has the potential to transform dentistry by preventing, reversing or restoring dental caries, which is one of the major health care problems. However, many challenges must be overcome, because many nano applications are still at the stage of experimental trials. The potential for misuse and abuse of this technology must not be overlooked, and formal interdisciplinary training programs should be instituted. The question of nanotoxicity also remains unresolved.

Conflicts of Interest

The authors declare that there is no conflict of interest.

Ethics Statement

Not applicable. This is a narrative review of published literature and involved no human participants or animals.

Author Contributions

All authors contributed to the design and conception of the review. Literature collection and analysis were performed by M.H.N. and L.A. The first draft of the manuscript was written by M.H.N. Critical review and editing of the manuscript for intellectual content were performed by M.H.N. and L.A. All authors read and approved the final manuscript.

Data Availability Statement

No new datasets were generated or analyzed during this review. All data discussed are available in the publications cited in the reference list.

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