REVIEW ARTICLE

From Nanoparticles To Natural Smiles: Transforming Restorative And Endodontic Practice.

Poonam Devi[1], Devendra Chaudhary[2], Harmeet Singh[3] , Navdeep[4]

Abstract

Nanotechnology is transforming the field of dentistry, particularly restorative dentistry and endodontics, through its influence on material science, diagnostics, and therapeutics. The use of nanoscale materials has enabled better mechanical strength, improved antimicrobial action, enhanced aesthetics, and even regenerative capabilities. This article reviews the current applications of nanotechnology in dental restorations and endodontic therapy, evaluates the benefits and limitations, and explores the future potential of this technology in clinical practice.

Keywords

Nanotechnology, Nanomaterials, Nano-scaffolds Nanocomposites, Tissue engineering, Nanoparticles

Introduction

The term "nanotechnology" refers to the design, production, and application of materials and devices at the nanometer scale, typically ranging from 1 to 100 nanometers. At this scale, materials exhibit unique physicochemical properties due to their large surface area-to-volume ratio and quantum effects. In dentistry, this translates to materials that are not only stronger and more durable but also biologically active and capable of interacting with tissues in ways traditional materials cannot [1,2] .

The evolution from macro to micro to nanoscale materials represents a paradigm shift in dental care, promoting precision, minimally invasive procedures, and improved clinical outcomes [3]

History

1959 – Richard Feynman introduces the concept of manipulating matter at the atomic level in his lecture, "There's Plenty of Room at the Bottom."

1981 – The invention of the Scanning Tunneling Microscope enables visualization and manipulation of atoms, marking the beginning of practical nanoscience.

1. Post graduate student
2. Principal, Professor & Head of the Department
3. Professor
4. Associate Professor
Department of Conservative Dentistry and Endodontics,

Corresponding Author:
Dr. Poonam Devi,
Post Graduate student,
Ph: +91 7339737237
Email: poonam883@gmail.com

Department of Conservative Dentistry and Endodontics, Maharaja Ganga Singh Dental College & Research centre, Sri Ganganagar, Rajasthan

1991 – Discovery of carbon nanotubes further accelerates research in nanomaterials.

2000 – Robert A. Freitas Jr. coins the term “nanodentistry”, envisioning nanorobots for diagnostics and treatment in dental care.

Early 2000s – Initial studies on nanoparticles and nanofillers begin to appear in dental material research, especially in restorative composites.

Mid-2000s – Development of nano-hydroxyapatite and nanostructured coatings for remineralization and enhanced bonding.

2010s – Widespread adoption of nanocomposites, antibacterial nanoparticles, and nano-scaffolds in both restorative dentistry and endodontics.

2020s – Focus shifts toward bioactive nanomaterials, targeted drug delivery, and smart nanodevices in clinical applications, with increasing research on regenerative endodontics.

Classification of Nanomaterials in dentistry

Based on Chemical composition	Based on Structure/Form	Based on Function
Inorganic Nanoparticles	Nanomers	Antimicrobial agents
Metallic Nanoparticles	Nanoclusters	Mechanical reinforcement
Polymeric Nanoparticles	Nanotubes / Nanowires	Bonding Enhancement
Quantum Dots	Nanorods	Drug Delivery
Bioceramic Nanoparticles	Nanocapsules / Nanoemulsions	Scaffold materials

(A) Nanotechnology in Restorative Dentistry

1. Nanocomposites

Dental nanocomposites incorporate nanoparticles such as silica, zirconia, or hydroxyapatite into resin matrices. These particles improve the filler-matrix interface, increasing wear resistance, surface polish, and fracture[4]. Filtek Supreme (3M ESPE) exemplifies this with improved esthetics due to light manipulation at the nanoscale [5].

2. Nanofillers in Adhesives

Incorporating nanofillers into bonding agents increases mechanical properties such as elastic modulus and cohesive strength. Nanofillers such as nanosilica, nanoclay, and nano-hydroxyapatite increase bon1ding agents' mechanical properties and reduce nanoleakage[6,7]
Types of Nanofillers used based on structure

Nanomeric (NM) Particles These are silica nanoparticles with sizes of 20-75 nm. They are non-agglomerated and chemically bonded to the resin matrix through coupling methacryloxypropyltrimethoxysilane agents like 3 (MPTS), enhancing compatibility and preventing particle aggregation during curing.

Nanoclusters (NCs) NC fillers consist of aggregates of smaller particles, such as silica-zirconia, with sizes ranging from 2 to 20 nm. These clusters enhance the composite's mechanical properties and are treated with coupling agents for better integration with the resin.

Application of nanofillers in dental adhesives

a) 5th Generation Light-Cure Self-Priming Adhesive Prime & Bond® NT™ (Dentsply): Combines primer and adhesive in one bottle for easier application and improved bond strength, with enhanced protection against microleakage.
b) 6th Generation Two-Step Self-Etching Adhesives NanoBond (Pentron Clinical Technologies): Uses nanofillers to enhance bonding and durability.
c) 7th Generation One-Step Self-Etching Adhesive G Bond (GC): A simplified, one-step system with nanofiller integration for improved bonding.

3. Nano Glass Ionomer Cement (GIC).

Nano-glass ionomer cements (Nano-GICs), introduced as an advancement over traditional GICs, incorporate nanoparticles like forsterite, nano-fluorapatite, and titanium to enhance mechanical strength, fluoride release, and antibacterial properties. Nano agglomerated glass improves compressive strength, while silver and zinc nanoparticles add anti-cariogenic effects. Resin-modified GICs with nanoclusters show improved aesthetics, polishability, bonding with dentin, and setting characteristics.

4. Nano-Varnish and sealants

Nanostructured hydroxyapatite and fluorapatite bioceramic nanofibers show enhanced solubility, promoting effective fluoride ion release, which helps in caries prevention when incorporated into sealants Nano-sealants also offer improved wear resistance and reduced polymerization shrinkage[8]. Another nanotechnology application is nano-filled light-curing varnishes, which protect glass ionomer cement (GIC) during its early maturation phase by minimizing water sorption and dehydration, thus enhancing mechanical properties. An example of this is EQUIA (Easy-Quick-Unique-Intelligent-Aesthetic)[9].

5. Nano polishing system

Traditional dental polishing employs micron-sized silica particles to smooth surfaces and prevent plaque accumulation. Inspired by semiconductor chemical-mechanical planarization (CMP), Gaikwad and Sokolov (2008) introduced silica/silver nanoparticles, achieving sub-nanometer surface smoothness, which significantly reduces bacterial adhesion and enhances antimicrobial action[10] compared to conventional methods.

6. Remineralization of Demineralized Enamel

Nano-hydroxyapatite (nHAp), due to its resemblance to natural enamel crystallites, helps restore mineral content in early carious lesions[11]. Products like Apagard and Remin Pro utilize this principle to achieve surface remineralization [12]. These nanoparticles can occlude dentinal tubules and are used for dentin hypersensitivity management.

7. Antibacterial Nanoparticles

Incorporating silver nanoparticles (AgNPs), zinc oxide (ZnO), and titanium dioxide (TiO_2) into restorative materials can inhibit cariogenic bacteria like Streptococcus mutans[13,14].These particles generate reactive oxygen species (ROS) and disrupt bacterial membranes, prolonging restoration lifespan by minimizing recurrent decay.

(B) Nanotechnology in Endodontics

1. Irrigation and Disinfection

Nanoparticles improve the antimicrobial efficacy of endodontic irrigants. Silver, chitosan, and zinc oxide nanoparticles are effective against biofilm-forming pathogens, especially Enterococcus faecalis and Candida albicans [15]. Chitosan nanoparticles also serve as chelating agents with sustained-release antimicrobial properties[16]

Nanoparticle	Mechanism
Silver (AgNPs)	Disrupts cell membranes, releases Ag^+ ions
Chitosan	Binds to bacterial membranes, inhibits growth
Zinc Oxide (ZnO)	Generates ROS under light
Bioactive Glass	Alkaline pH, releases Ca^{2+}/PO_4^{3-} ions

2. Intracanal Medicaments

Nanoparticles incorporated into calcium hydroxide pastes or as independent medicaments enhance penetration into dentinal tubules and increase antibacterial action[17]. Nanosilver and curcumin nanoparticles are also being explored for their dual anti-inflammatory and antimicrobial properties.

Calcium Hydroxide + AgNPs	Silver nanoparticles	Enhanced antibacterial efficacy
Chitosan Hydrogels	Chitosan NPs	Biocompatible, reduces biofilm adherence
ZnO-Polyethylene Glycol	Zinc oxide NPs	pH-dependent ROS generation

3. Nano-Sealers and Fillers

Bioceramic-based sealers like BioRoot RCS and EndoSequence BC contain nanoscale calcium silicate particles that show excellent flow, sealing ability, and bioactivity. These materials promote the formation of hydroxyapatite at the sealer-dentin interface, enhancing periapical healing and biocompatibility.[18]

Nano-diamond GP (NDGP)	Amoxicillin-conjugated NDs	Antibacterial, improves mechanical strength
GuttaFlow Sealer	AgNPs, SiO_2 NPs	Alkaline pH (12.8), resists microleakage
Bioceramic Sealers	Bioglass NPs	Forms hydroxyapatite, enhances sealing

4. Regenerative Endodontics and Scaffolds

Tissue engineering approaches utilize nanofibers and self-assembling peptide hydrogels to create scaffolds that support cell attachment, proliferation, and differentiation. Nanostructured hydroxyapatite scaffolds and drug-loaded nanoparticles are being researched for pulp-dentin regeneration and apexogenesis.[19,20]

Nanohydroxyapatite	Mimics dentin minerals, promotes odontogenesis	Reparative dentin formation in pulp capping
Graphene Oxide	Enhances scaffold mechanical strength	Supports DPSC proliferation
Melanocortin Peptides	Reduces inflammation, stimulates fibroblasts	Accelerates pulp healing

(C) Diagnostic Applications of Nanotechnology

- Nanosensors and quantum dots are emerging tools for early caries detection and biofilm mapping.[21,22]

- Nanoprobe-based diagnostics can identify pathogenic bacteria in root canals at the molecular level, allowing personalized disinfection strategies.

Advantages of Nanotechnology in Dentistry

- Enhanced mechanical durability
- Superior esthetics
- Bioactivity and remineralization
- Targeted antimicrobial action
- Potential for real-time diagnostic

Challenges and Concerns

- Toxicity and Biocompatibility: Long-term effects of nanoparticles, especially metallic ones like silver and titanium dioxide, are not fully understood.
- Lack of Standardization: Differences in synthesis and characterization methods hinder reproducibility and comparability.
- Cost and Accessibility: Nanomaterials often require expensive production and are not yet widely available in all regions.
- Regulatory Hurdles: Approval by regulatory bodies like FDA or CE is often time-consuming and requires extensive research.

Future Prospects

- Nanorobots may enable automated caries removal, plaque elimination, or even single-cell diagnostics.
- Smart nanomaterials with stimuli-responsive behavior (pH or temperature-sensitive) are being developed for drug delivery and tissue engineering.
- Artificial Intelligence and Nanotechnology are expected to merge for highly individualized dental care and predictive treatment models[23,24] .

Conclusion

Nanotechnology represents a transformative innovation in restorative dentistry and endodontics. From improving material performance to enabling tissue regeneration and precise microbial control, the possibilities are vast. While challenges remain, ongoing research and interdisciplinary collaboration are rapidly moving this field from bench to chairside, promising a future of more effective, patient-centered dental care.

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