Review Article

Silica Nanoparticles: "One More Step Towards the Dental Holy Grail": A Narrative Review

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Abstract:

Background: This article aims to review the SNPs applications in nanomaterial and nano formulations in restorative dentistry, discussing their effect on physicochemical properties, biocompatibility and ability to nano carry bioactive substances.

Review Findings: The addition of SNPs in Polymethyl Methacrylate increases microhardness, fracture toughness and decreases Candida Albicans adhesion. Polymerization shrinkage decreased when SNPs were added in composite resin with increase flexural strength, flexural modulus, wear resistance. GIC cement having limitations of microleakage was overcome with the help of incorporation of HTCC-MSN & Nano Zro2-Sio2-HA. Incorporating SNPs into bioactive glasses showed tissue remineralization potential. Experimental adhesives with higher concentration of particles for bonding lowered risk to dental enamel during bracket detachment & reduced friction between tooth and bracket.

Conclusion: SNPs incorporation improved the biological and physiochemical and mechanical properties of dental materials & over-ruled the drawbacks of previous dental material. Different studies in this review concluded that SNPs of smaller sizes particularly ranging between 78nm and 424 nm provided the advantage of being biocompatible and non- cytotoxic.1

Keywords: Nanomaterial, Silica nanoparticles, Zn doped mesoporous silica nanoparticles (Zn-MSNs)

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INTRODUCTION:

What Are Silica Nanoparticles? In recent years, advancements in medical nanotechnology have significantly enhanced the ability to prevent, diagnose, and treat various diseases at the nanoscale. Among the numerous nanomaterials utilized in biomedical applications, silica nanoparticles (SiNPs) have garnered particular interest in the field of dentistry1.

A natural, incidental, or manufactured material that contains particles in an unbound state, aggregate, or agglomerate and where at least 50% of the particles in the number size distribution have one or more external dimensions in the range of 1 to 100 nm is referred to as a "nanomaterial" according to the European Commission's recommendation. NPs were shown to have improved antibacterial properties due to their positive charge and larger surface area2.Antimicrobial nanoparticles with a wide range of benefits, including a high surface-area- to-volume ratio, extremely small sizes, and superior chemical and physical properties, have been developed to address the shortcomings of traditional antibacterial agents and produce encouraging endodontic results.
By combining the fields of nanomaterials research and biotechnology, nanoparticles have the potential to significantly improve oral health by offering diagnostic and preventative tools. The use of nanomaterials has been controversial for years due to safety concerns, but research has shown that there are more benefits than drawbacks to using them3. Their strong delivery mechanisms, huge specific surface area, ease of synthesis and amplification, and ease of surface modification are some of their distinctive features4.

Organic nanoparticles: Silica nanoparticles, chitosan, and poly (lactic) co-glycolic acid are examples of organic nanoparticles. Non-organic nanoparticles: glass nanoparticles that are bioactive, Mesoporous calcium silicate, hydroxyapatite nanoparticles, metal nanoparticles, zirconia, TiO_2, CuO, iron compound (FeO_x), silver nanoparticles (AgNPs), and metal oxide nanoparticles.
Because of their high surface area, low toxicity, and great biocompatibility, silica nanoparticles have had a significant evolutionary impact in dentistry, particularly in conservative dentistry as opposed to endodontics. They are frequently employed as polishing agents because they can reduce the roughness of the polished substrate and as dental fillers in a variety of restorative materials to enhance mechanical qualities. In general dentistry, silica powder is used as a polishing agent to smooth out the tooth's rough surface and stop food buildup and plaque development. Recent years have seen a huge increase in the use of mesoporous silica nanoparticles (MSNs), or silica nanoparticles with mesopores. It is a unique and potential drug carrier because of its facile independent functionalization of the surface, internal and exterior pores, gating mechanism of the pore opening, and uniform and changeable pore size. There have been several published reviews on the use of MSNs to increase drug solubility in controlled/sustained drug delivery systems in biomedicine.5

Nanoparticles in dental application: Composites, Irrigation, Inter-appointment Intracanal medicaments, Obturation, Bulk filler, Sealers etc. Various nanoparticles used in Endodontics

This article aims to review the SNPs applications in nanomaterial and nano formulations in dentistry, discussing their effect on physicochemical properties, biocompatibility and ability to nano carry bioactive substances. different nanomaterials and application of its in different branches of dentistry.

SILICA NANO PARTICLES USES IN DENTISTRY

A more recent method of producing sophisticated nanomaterials has been the creation of a biomimetic approach based on nanotechnology to mimic natural biomaterials. As adaptable and dependable materials for many caries types, dental resin composites have been employed extensively in place of amalgam alloys. The impregnation of silanized UHA with silica nanoparticles significantly improved the mechanical properties of dental composite, further demonstrating the reinforcing efficiency of UHA. In order to create dental resin composites with enhanced mechanical qualities and possible bioactivity, the new urchin-like hydroxyapatite may be a useful and promising filler 6.
Its mechanical qualities, minimal polymerization shrinkage, strong abrasion resistance, and surface hardness can all be greatly improved by a composite resin matrix. According to a newly published study,

the mechanical and aesthetic qualities of GIC were enhanced by the addition of fluoro-aluminosilicate glass nanoparticles. Recently, Nano ionomers (Ketac™ Nano; 3MESPE) have been marketed for clinical use7.

Nano-inorganic fillers SiO2, ZrO2, HA, and Al2O3 were added to the tested composites in a constant proportion (40% by weight). The results showed that dental composites reinforced with silica nanoparticles had superior properties compared with other types of prepared nanocomposites in terms of diametrical tensile and compressive strength8. A related study utilized silica nanoparticles ranging from 20 to 50 nm in size, with filler mass fractions of 20%, 30%, 40%, and 50%. These composites were compared to a conventional composite containing silica particles sized between 10 and 40 µm. The incorporation of nanosized silica enhanced mechanical properties, with mass fractions up to 40% leading to improved fracture toughness, flexural strength, and hardness compared to the control.

Incorporating SiO2 nanoparticles into FRC resin phase not only had a significant effect on its mechanical behaviour but also led to a more proper impregnation of fibers9.In situ clinical study showed that composites with QASi antibacterial particles significantly reduced demineralization in enamel adjacent to a 38-µm artificial gap in an in-situ gap model in comparison to a conventional composite, with mineral loss evaluated by cross sectional microhardness testing in the laboratory. Aditionally, for each individual participant, the side with the test composite had less evaluated mineral loss in the enamel slabs than the side with the control composite. Consequently, composites with QASi nanoparticle technology have the potential to reduce the occurrence of secondary caries10.

Sol-gel was used to create Zn-doped mesoporous silica nanoparticles (Zn-MSNs), which have a large specific surface area, structured mesoporous channels, and a uniform distribution of Zn. Without sacrificing the dental resins' cytocompatibility, the addition of Zn-MSNs could greatly enhance their mechanical and antibacterial qualities. Out of all the composites, 15 weight percent Zn-MSNs showed the highest mechanical qualities, optimal curing depth and degree of conversion, outstanding antibacterial activity, and minimal shrinkage. A suitable reinforcing filler for dental resin composites would be the produced Zn-MSNs, given their improved mechanical characteristics and antibacterial activity11.

ENDODONTICS

Through the use of nanotechnology, endodontic materials' qualities can be improved by adding antibacterial nanoparticles, which can stop infections and root canal breakdowns. According to a recent study, biopolymeric nanoparticles (NPs) significantly reduced the amount of bacteria in root canal disinfectants. Another study found that adding QPEI (quaternary ammonium polyethylenimine) nanoparticles enhanced the root canal sealer's antibacterial effectiveness against Enterococcus faecalis strain biofilms.

The long-term antibacterial capability of the nanoparticle-based method for treating endodontic infections is shown for the first time in this proof-of-concept study. By combining AgNPs@SiO2 with appropriate cleaning agents, which retain their effectiveness when used as a single solution, biofilm regrowth can be prevented. It has been demonstrated that the AgNPs@SiO2-containing solutions are less cytotoxic than the ones that are typically utilized. This study lays the foundation for an infection treatment procedure that can eliminate the smear layer from instrumented root canal dentinal surfaces and prevent bacterial recurrence for at least seven days following treatment.. Meanwhile, in contrast to the current treatment method where NaOCl and EDTA are used sequentially, the developed solutions allow one-step handling by the simple mixing of two pre-irrigation solutions (NaOCl, and AgNPs@SiO2 +

Tris + EGTA or SP) right before the treatment, which hence decreases the treatment time and is beneficial to both patients and dentists12.

DENTAL MATERIAL

In addition to improving the mechanical properties of GICs, the addition of chitosan nanoparticles to the GICs increased fluoride and induced moisture. Silica nanoparticles (10% and 15%) are added to the polymeric bonding system to boost hybrid layer formation within the dentin and strengthen the bond as compared to the unmodified adhesive resin13.

DISCUSSION

Nanoparticles, particularly silica nanoparticles (SNPs) and mesoporous calcium-silicate nanoparticles (MCSNs), hold significant promise in restorative dentistry due to their unique properties and multifunctional applications.

Silica Nanoparticles (SNPs)
SNPs have garnered attention for their ability to enhance the physicochemical properties of dental materials. Their applications span diagnostic, preventive, restorative, and conservative dentistry. Here are some key points regarding SNPs:

- **Chemical Characteristics:** Silica (SiO_2) is a widely available and inexpensive compound, classified by the FDA as "generally regarded as safe" (GRAS), which makes it suitable for biomedical applications.5
- **Applications in Dentistry:** Traditionally, silica has been used in dental composites as a filler due to its favourable physical and optical properties. It enhances the strength, durability, and aesthetic qualities of restorative materials14.
- **Controlled Release:** SNPs can facilitate the high loading efficiency and controlled release of active substances, which could improve the therapeutic effects of dental materials.

Mesoporous Calcium-Silicate Nanoparticles (MCSNs)
MCSNs represent an advanced class of materials specifically designed for root canal applications. Their unique nanostructure confers several beneficial properties:

- **Injectability:** MCSNs can be easily injected into the root canal system, allowing for precise placement and distribution.
- **Mineralization:** They promote the formation of hydroxyapatite, which is crucial for bone regeneration and repair.
- **Antibacterial Properties:** MCSNs can infiltrate bacterial biofilms and continuously release calcium and silicon ions, creating a weak alkaline microenvironment that has antibacterial effects.
- **Drug Delivery:** MCSNs serve as effective carriers for drug delivery, enhancing the therapeutic efficacy of treatments aimed at dental infections.

Enhancements with Silver and Zinc
MCSNs modified with silver (Ag) and zinc (Zn) have shown promising results:

- **Physicochemical Properties:** These modified MCSNs exhibit ideal characteristics that enhance their effectiveness in clinical applications.
- **Antibiofilm Activity:** The presence of Ag and Zn contributes to significant antibiofilm activity by disrupting bacterial cell membranes, leading to bacterial cell death15.

Future Directions
The potential applications of SNPs and MCSNs in dentistry are vast. However, further research is essential to:

- ***Optimize Properties*:** Investigate the ideal formulations and concentrations of nanoparticles for specific dental applications.
- ***Clinical Studies*:** Conduct clinical trials to assess the long-term efficacy and safety of these materials in restorative procedures.
- ***Regulatory Approvals*:** Navigate the regulatory landscape to ensure that innovative nanoparticle-based materials meet safety and efficacy standards for clinical use.

Additional Applications: Silica has also been added to bio-ceramic and hydroxyapatite artificial bone scaffolds, potentially improving osteoconductivity and proliferation. A recent study produced mesoporous silica xerogels using the sol gel procedure with varying surface areas (401, 647, and 810 m2/g, respectively) and discovered that osteoblast synthesis of attachment proteins increased along with proliferation. In summary, the incorporation of silica nanoparticles and mesoporous calcium-silicate nanoparticles into dental materials represents a significant advancement in restorative dentistry, with the potential to improve treatment outcomes and patient care.

Although silica is already utilized in many applications and is thought to be non-cytotoxic to the organism, it is hypothesized that at the nanoscale, the particles may diffuse into tissues more quickly, leading to increased cytotoxicity. However, there is disagreement regarding how particle size affects toxicity. According to the research in this review, SNPs with varying sizes—between about 78 and 424 nm—were not cytotoxic to oral cells, and their size did not appear to affect their physicochemical and antibacterial qualities1.

CONCLUSION

SNPs particularly of smaller sizes ranging between 78 nm & 424nm provided the advantage of being biocompatible and non-cytotoxic. While the incorporation of such SNPs has improved the biological, physiochemical and mechanical properties of dental materials & has over-ruled the drawbacks of previous dental material.

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