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Clinical Application of Biocompatible Polymer-Based Nanomaterials for Restorative Dentistry Review

Dr.Nemah Mohammed Albeirutty[1], Dr.Shaza Jamil Ahmad Ashqar[2], Dr.Majed Mohammed Awadi[3], Dr.Ahmed saeed babonji[4], Dr.Tareq Saleh Sagheer Alzahrani[5], Dr.Hanan Abdullah Rajab Turkstani[6], Dr.Heba Moneib Alkhateeb[7], Dr.Rasha Mohammed Alidrissi[8], Dr.Lubna Siddig Emam[9], Dr.Abrar Ahmed Khayyat[10], Dr.Sawsan Ghaith Alsharif[11], Dr.Nouf Mohammad alhobani[12], Dr.Hassan sidig Emam[13], Dr.Hasan Hamed Al Abdali[14], Dr.Jamal Mousa b Alotaibi[15]

[1]Consultant restorative dentistry at East Jeddah Hospital
[2]Phc in makkah, General dentist
[3]General dentist at Al-hindawiyah PHC
[4]PHC hindawiyah, General dentist
[5]Dentist at Asfan PHC
[6]General Dentist at Molaqiya PHC
[7]General dentist at Asfan PHC
[8]General dentist at Khulais PHC
[9]General dentist at Al-Hindawiyah PHC
[10]General Dentist at Um Aljerem PHC
[11]General Dentist at Al hindawiyah PHC
[12]General dentist at New Sabia PHC
[13]Umm al bark PHC, General dentist
[14]General Dentist at Um Aljerem PHC
[15]Al-Shohadaa Al-Janoubia PHC, General Dentist

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ABSTRACT
Dental composite resins are widely employed restoratives, enabling the excision of only the diseased and impaired carious tissue during tooth replacement. This allows the patient to retain a greater quantity of their natural tooth structure in contrast to conventional cavity preparation methods. Nanomaterials embody an innovative notion that entails the modification of materials at the atomic or molecular level. At the nanoscale, the chemical, biological, and physical properties of an atom diverge from those of its naturally occurring compound form. The main goal of highlighting the integration of nanomaterials is to enhance the identification, treatment, and prevention of illness recurrence. The primary aim of using nanoparticles in composites is to improve their strength, wear resistance, and microhardness. This application also reduces polymerization shrinkage. Nanomaterials can enhance mechanical properties, durability, and adhesion between dentin and restoration. This study aims to clarify the diverse research investigations and experiments conducted on the use of nanoparticles in restorative dentistry to understand the versatility and feasibility of these materials.

Keywords: chemical, biological, physical, properties, durability

INTRODUCTION

Tooth restoration is a primary operation in dental care. It pertains to the restoration of the teeth's normal structure, ensuring that the treated or restored teeth replicate the characteristics and functionality of the original, unaffected teeth. The concepts of tooth preparation are designed to assist an operator in creating a cavity that allows the restoration to seamlessly integrate, maintain its position over time, and replicate the normal function and behavior of the tooth [1]. Historically, the cavity made according to the principles of endodontics was predominantly filled with amalgam. Amalgam is an alloy composed of silver and mercury in a 3:7 ratio. It was perpetually enhanced through the incorporation of filler particles. Amalgam has historically been the primary restorative material in endodontics; however, advancements in technology and knowledge have led to its widespread replacement by dental composite resins, which are superior, more versatile, aesthetically pleasing, and considerably stronger alternatives.

The imperative to create prostheses and restorations that not only replicate the appearance and function of real teeth but also integrate harmoniously with the biological tissues of the oral environment has played a crucial role in the evolution of dental materials. The paramount criterion for dental materials is biocompatibility, defined as the capacity of a material to elicit a suitable host response in certain applications [3]. In dentistry, the materials used must facilitate healing and integration with surrounding tissues while being non-toxic, non-carcinogenic, and non-immunogenic.The advancement of biocompatible dental materials is significantly impeded by the complex characteristics of the mouth cavity, which is defined by its varied microbial flora, fluctuating mechanical loads, and continual exposure to saliva and other fluids.Although effective, traditional materials such as amalgam and standard composites may exhibit inadequate biocompatibility, potentially resulting in adverse tissue reactions, hypersensitivity, or eventual restorative failure [3].Recent advancements in polymers, ceramics, and nanotechnology have significantly enhanced dental materials, providing increased biocompatibility. Innovations such as surface-modified titanium implants, calcium phosphate-based cements, and bioactive glasses have been examined for their capacity to actively enhance tissue regeneration and healing processes while maintaining the structural integrity of teeth. Furthermore, the objective of employing antimicrobial treatments and protective coatings is to diminish the probability of infection and enhance the longevity of dental restorations.This study establishes the groundwork for a comprehensive examination of the current status of biocompatible dental materials, their mechanisms of action, therapeutic applications, and future prospects in this swiftly advancing domain. The development of biocompatible materials is a crucial area of research in restorative and preventive dentistry due to the increasing demand for safer and more effective dental treatments.This study examines the biocompatibility of dental materials by synthesizing findings from various scientific studies, systematic reviews, and clinical trials [5].

Dental composite resins typically consist of dimethacrylate monomers (Bis-GMA, TEGMA, and UDMA) and multi-functional filler materials, which improve elastic modulus, augment strength and wear resistance, and reduce polymerization shrinkage of the restoration. Filler particles can be categorized into macro fillers, micro fillers, micro-hybrid fillers, and nanofillers. Similar to the enhancement of amalgam with copper, composites have been refined through the incorporation of diverse filler elements, including nanofillers [5].

Review

Polymers are macromolecules made up of repeated monomeric subunits that have outstanding characteristics. Innovation in biomaterials research encompasses applications in tissue engineering, nanotechnology, and the administration of bioactive molecules for the healing and regeneration of diverse tissues. Nanomaterials are employed to manipulate substances at the atomic or molecular scale. Nonetheless, at the nanoscale, the chemical, biological, and physical properties of an atom differ from those of its naturally occurring compound forms [5]. The human tooth structure comprises enamel, which consists of 96% hydroxyapatite with particle sizes ranging from 10 nm to 200 nm. Intertubular dentin measures 2-5 nm in thickness and 60 nm in length. Enamel and dentin are interconnected by collagen fibrils about 20-75 nm in length. These attributes establish a robust foundation for the fundamental necessity of research uses of nanomaterials in dentistry. Nano dentistry refers to the application of nano-materials in the field of dentistry. The primary objective of emphasizing the utilization of nano-materials is to facilitate the detection, treatment, and prevention of the recurrence of pathology (secondary caries). The emergence of the digital era and heightened patient expectations for aesthetics and usefulness have presented challenges to the domain of engineered nanomaterials [6]. Nanocomposites are biomaterials wherein at least one phase exhibits dimensions in the nanoscale scale. The dimensions of nano-materials vary from 5 nm to 100 nm. The use of these filler particles results in color modification and enhances the flexural strength of the composite resin restoration. A multitude of nano-materials is presently undergoing experimental investigation to assess their potential to improve products across several fields. In dentistry, specifically restorative dentistry, nanomaterials are utilized to produce nanocomposites, glass ionomer cement, and endodontic sealers. The primary objective of using nano-materials in composites is to enhance their strength, wear resistance, and microhardness, while simultaneously minimizing polymerization shrinkage; nevertheless, the extent of polymerization shrinkage is contingent upon the chemical structure and manufacturing process of the composite [8]. Research indicates that the optimal weight percentage of nanofillers should not be surpassed, since no enhancement in mechanical qualities can be attained beyond that point. Nanomaterials can improve the mechanical characteristics, longevity, and binding strength between dentin and restoration. The synthesis of nanomaterials mostly occurs through two approaches: the top-down method, which involves reducing bulk material to nanometric dimensions using various techniques, and the bottom-up method, which entails aggregating individual atoms.

Nanotechnology has evolved significantly from a theoretical notion introduced by Richard Feynman to its integration into all facets of life, including dentistry. Traditional dental technology has been enhanced by the transformative concepts of nanotechnology. These ideas catalyze a paradigm shift in the research perspective of nanotechnologists across several dental disciplines, including prosthodontics and orthodontics. Dental practitioners primarily concentrate on the preventive treatment of dental cavities and periodontal disease. When a tooth or periodontium is afflicted by an infectious condition, the primary objective of treatment is to eliminate the pathogens, excise decayed tissues, and repair them to ensure enduring functionality in the oral cavity. Various methodologies, including top-down, bottom-up, biomimetic, and functional approaches, were examined for each facet [9].

Optimal dental health necessitates adequate diet, which correlates with an enhanced quality of life. Teeth are undeniably a fundamental component of oral health. Creating biocompatible nanoproducts necessitates a thorough evaluation of the anatomy and physiology of the target area, specifically the teeth and oral cavity. The proximity of nanomaterials to nanoparticles determines the nanomaterial's outcome within the body. The anatomy, structure, and chemical composition of human dental tissues are varied, and comprehending each component and the specific material abundance in each layer offers insight into the precise formation of nanomaterials tailored to the requirements of the target layer. The tooth can be primarily categorized as Enamel, Dentin, Pulp, Cementum, and Periodontal ligament, from external to internal layers. Tooth enamel is the most mineralized and robust crystalline structure composed of hydroxyapatite (HA), characterized by exceptionally strong intermolecular forces. The composition consists of 96 wt.% inorganic material, 4 wt.% organic material, and water. Approximately 70% of the inorganic composition is present in dentin. It comprises HA biocomposites that envelop the collagen fibers, which is why HA is the most prevalent material for dental products, particularly in nanoproducts [10].

Paiva et al. [11] sought to formulate polyacids by photo-reducing Ag nanoparticles within a polyacrylate solution of standard glass ionomer cement (GIC) in a single step, preserving antibacterial efficacy while assessing the handling and mechanical properties of the Ag-enhanced GIC relative to conventional GIC. The altered restoration was evaluated against S. mutans. The investigation revealed that the GIC augmented with AgNP exhibited remarkable antibacterial efficacy. The restoration operated on the concept of diffusion, signifying the dissolution of Ag ions (oxidative) from the cement matrix; this resulted in the conclusion that GIC augmented with silver nanoparticles can inhibit caries and prevent biofilm formation on their surface [11]. Stewart [12] sought to render the restoration antimicrobial, so enabling it to protect against the risk of subsequent caries. He integrated octenidine dihydrochloride (OCT) into drug-eluting mesoporous silica nanoparticles (DMSNs). These were constructed utilizing the bottom-up synthesis process. OCT is said to exhibit great biocompatibility [12], and no microbial resistance has been identified to yet. The researchers developed a localized dental resin glue utilizing silica nanoparticles, which is limited to the healed tooth surface while providing prolonged medication release, hence reducing systemic exposure. Their investigation demonstrated that the long-term prevention of secondary caries can be accomplished by the repair itself [13]. Yue et al. [14] created a self-healing adhesive with antimicrobial and remineralizing properties, and for the first time, assessed the impact of including microcapsules such DMAHDM and NACP nanoparticles. Microcapsules with self-healing properties were produced, using polyurea-formaldehyde (PUF) shells made of 10% DMAHDM and 20% NACP. The single-edge V-notched beam technique was employed to determine fracture toughness, Kic, and crack-healing efficiency. Yue et al. [14] accomplished three outcomes with the newly formulated adhesive resin: autonomous fracture healing, antimicrobial properties, and remineralization by the incorporation of calcium phosphate nanoparticles. The engineered adhesive diminished the colony-forming units of microcosm biofilms by four orders of magnitude relative to the standard control. The innovative approach of utilizing triple agents (self-healing microcapsules + DMAHDM + NACP) to repair fractures and inhibit caries is anticipated to be applicable to various dental adhesives, cements, sealants, and composites [14].

Advancements in synthetic biopolymer composition have facilitated the creation of innovative materials that exhibit superior tissue responsiveness and integration, while also being biodegradable and removable from the system, thereby allowing for proper tissue integration as the material degrades without adversely affecting biological systems.Seven Ongoing efforts aim to create scaffold compositions suitable for biological systems with minimal or no adverse effects on live organisms [15].

Polymers are macromolecules composed of covalently linked repeating monomeric components. They may exhibit amorphous or crystalline structures, with linear, branched, or cross-linked chains. Their mechanical properties can be precisely controlled, enabling the attainment of preferred attributes according to application specifications. Recently, polymers have been utilized to fabricate microneedles (MNs), hydrogels, microcapsules, microspheres, and fibers [15].

Enamel loss causes dentin exposure, resulting in hypersensitivity to thermal stimuli. Modified silica nanoparticles are employed to address dental hypersensitivity by facilitating remineralization to halt the progression of decay. In addition to HA, hydraulic calcium silicate (hCSCs) re-mineralizes demineralized dentin and is increasingly favored by dentists for its enhanced strength, superior biological capabilities, and favorable physicochemical characteristics [16]. Furthermore, hCSCs possess the ability to re-mineralize demineralized dentin, hence facilitating the stabilization of the tooth and preventing the progression of infection to the pulp. Zhang et al. introduced nano-HA toothpaste for the remineralization of teeth to inhibit caries formation utilizing an artificial caries model. Huang et al. conducted a comparative investigation between nano-HA and sodium fluoride, demonstrating the superior efficacy of nano-HA in remineralization [17]. Regrettably, the chemical can infiltrate only a limited depth into the dentin tubules, yielding incomplete protection. Versatile and new dendrimer-type nanotherapeutics were developed for remineralization. Liang et al. examined the remineralization effects of poly (amidoamine) (PAMAM) dendrimer combined with a bonding agent including NACP in a cyclic artificial saliva/lactic acid environment. Following a 20-day period, a notable enhancement in the dentin layer corroborated the proposed concept [17]. Liposomes have been extensively studied in the context of biofilms; Nguyen et al. demonstrated that polysaccharide (hyaluronic acid)-coated liposomes exhibit superior adhesion to teeth compared to untreated liposomes [18]. The cationic charged liposomal membrane, through the attachment of pectin, hyaluronic acid, and similar substances, enhances adherence to dental hydroxyapatite, hence prolonging enamel retention. Furthermore, the hydrophilic coating enhances the stability of biofilms inside the salivary microenvironment [18].

CONCLUSION

Nanotechnology employs mechanics to regulate the dimensions and morphology of particles within the desired nanoscale for achieving certain objectives. Initially, it was primarily utilized in the domains of material physics and chemical engineering; nevertheless, over time, biological scientists acknowledged its extensive benefits and investigated its applications in various professions. The application of nanotechnology in dentistry is referred to as 'Nanodentistry.' It is transforming every facet of dentistry. It comprises therapeutic and diagnostic instruments, along with supportive assistance, to uphold oral hygiene utilizing nanoparticles. Research in nanodentistry is progressing gradually and comprehensively, focusing on the synergistic application of innovative polymers, natural polymers, metals, minerals, and pharmaceuticals. These materials, in conjunction with nanotechnology, facilitate the investigation of nano dental adducts in prosthodontics, regeneration, orthodontics, and other applications. Furthermore, the drug release capabilities of the nano dental adduct confer a distinct advantage to dentistry compared to traditional methods. Nano dentistry has proliferated throughout all branches of dentistry.

REFERENCES

1. Nanotechnology: convergence with modern biology and medicine. Roco MC. Curr Opin Biotechnol. 2003;14:337–346.
2. Bio-inspired dental fillings. Deyhle H, Oliver B, Buser S, et al. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. 2009;7401
3. Dentin: structure, composition and mineralization. Goldberg M, Kulkarni AB, Young M, Boskey A. Front Biosci (Elite Ed) 2011;3:711–735.
4. Nanodentistry: a paradigm shift-from fiction to reality. Kumar PS, Kumar S, Savadi RC, John J. J Indian Prosthodont Soc. 2011;11:1–6.
5. Understanding nano-anatomy of healthy and carious human teeth: a prerequisite for nanodentistry. Gaiser S, Deyhle H, Bunk O, White SN, Müller B. Biointerphases. 2012;7:4.
6. Parirokh M, Torabinejad M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview -part I: vital pulp therapy. Int Endod J. 2018 Feb;51(2):177-205.
7. Parate KP, Naranje N, Vishnani R, Paul P. Polyetheretherketone Material in Dentistry. Cureus. 2023 Oct 4;15(10):e46485.
8. Stein PS, Sullivan J, Haubenreich JE, Osborne PB. Composite resin in medicine and dentistry. J Long Term Eff Med Implants. 2005;15(6):641-54.
9. Wataha JC. Principles of biocompatibility for dental practitioners. J Prosthet Dent. 2001 Aug;86(2):203-9.
10. Composite resin reinforced with silver nanoparticles-laden hydroxyapatite nanowires for dental application. Ai M, Du Z, Zhu S, Geng H, Zhang X, Cai Q, Yang X. Dent Mater. 2017;33:12–22.
11. Antibacterial properties and compressive strength of new one-step preparation silver nanoparticles in glass ionomer cements (NanoAg-GIC) Paiva L, Fidalgo TK, da Costa LP, et al. J Dent. 2018;69:102–109.
12. Low-level exposure of MRSA to octenidine dihydrochloride does not select for resistance. Al-Doori Z, Goroncy-Bermes P, Gemmell CG, Morrison D. J Antimicrob Chemother. 2007;59:1280–1281.
13. Responsive antimicrobial dental adhesive based on drug-silica co-assembled particles. Stewart CA, Hong JH, Hatton BD, Finer Y. Acta Biomater. 2018;76:283–294.
14. Novel dental adhesive resin with crack self-healing, antimicrobial and remineralization properties. Yue S, Wu J, Zhang Q, et al. J Dent. 2018;75:48–57.
15. Drukteinis S. Hydraulic calcium silicate-based materials for root canal obturation. Clin. Dent. Rev. 2022;6:1.
16. Lv K.L., Zhang J.X., Meng X.C., Li X.Y. Remineralization Effect of the Nano-HA Toothpaste on Artificial Caries. Key Eng. Mater. 2007;330–332:267–270.

17. Huang S., Gao S., Yu H.J.B.m. Effect of nano-hydroxyapatite concentration on remineralization of initial enamel lesion in vitro. Biomed. Mater. 2009;4:034104.
18. Liang K., Weir M.D., Reynolds M.A., Zhou X., Li J., Xu H.H. Poly (amido amine) and nano-calcium phosphate bonding agent to remineralize tooth dentin in cyclic artificial saliva/lactic acid. Mater. Sci. Eng. C. 2017;72:7–17.