Nanofillers in Dentistry

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Abstract

Nanotechnology is the molecular and atomic-level manipulation of matter. It has the potential to alter medicine and dentistry. Many researchers and dental practitioners have noticed the promising effects of nanotechnology on the prevention, diagnosis, and treatment of oral diseases. When nanotechnology is incorporated into dentistry, a new branch of practice known as nanodentistry emerges. By utilizing nanotechnology, dental materials can gain better characteristics and be enhanced. Nanodentistry creates any product from the base up using atomic components. There are many options, including nano-impressions, nanoceramics, and nanocomposites. Grains, fibers, crystals, nanoholes, films, and atoms are all forms of nanomaterials. Fillers that are nanoparticles in size and have low agglomeration and high dispersion can boost mechanical and antimicrobial capabilities. Nanofillers offer superior flow, hydrophilic characteristics, and reduced spacing at dental margins than traditional fillers. Nanofillers are now used to create more precise dental and gum impressions. By using nanofillers, a new class of dental restorative materials may be made with the ability to inhibit the production of cariogenic biofilm. This chapter aims to overview nanotechnology and its application in dentistry. In the following, we will mention the types of nanoparticle forms used in dentistry, focusing on nanofillers and their application. Ultimately, we will discuss the future use of nanotechnology and nanofillers in dentistry.

Keywords

Nanotechnology · Dentistry · Dental materials · Restorative dentistry · Nanodentistry · Nanofillers

Introduction

Nanotechnology has revolutionized various fields, including medicine and dentistry, by enabling the manipulation of materials at the nanoscale level. Incorporating nanofillers has led to significant advancements in dental materials, improving their mechanical, physical, and antimicrobial properties (Omid et al. 2024). Nanofillers are particles with at least one dimension in the nanoscale range (1–100 nm) and have gained increasing attention due to their unique properties and potential applications in dental restorative materials, impression materials, and bone grafts (Khurshid et al. 2015). The use of nanofillers in dentistry offers several advantages over traditional fillers. Nanofillers have a high surface area to volume ratio, which allows for better interaction with the polymer matrix, resulting in enhanced mechanical properties such as increased strength, hardness, and wear resistance (Polini et al. 2013). Moreover, nanofillers can improve the aesthetic properties of dental materials by providing better polishability, translucency, and color stability (Singh et al. 2021). Incorporating nanofillers with antimicrobial properties, such as silver and zinc oxide nanoparticles, can also help prevent the formation of dental caries and periodontal diseases (Bapat et al. 2019).

The application of nanofillers in dentistry is not limited to restorative materials. Nanofillers have been used to develop dental impression materials, providing improved flow, hydrophilicity, and reduced marginal gap formation (Ghods et al. 2022). Despite the numerous benefits of nanofillers in dentistry, some challenges and concerns need to be addressed. Nanofiller-containing dental materials' long-term stability and biocompatibility require further investigation (Schmalz et al. 2017). Additionally, the potential health risks associated with using nanoparticles, such as their ability to cross biological barriers and accumulate in organs, should be carefully evaluated (Buzea et al. 2007). This chapter aims to provide an overview of nanofillers and their applications in dentistry. The following sections will discuss the types of nanofillers used in dentistry, their synthesis methods, and their incorporation into various dental materials. The benefits and drawbacks of nanofillers in dentistry will also be explored, along with future trends and research directions in this field.

Nanotechnology

Nanotechnology research has advanced dramatically over the past decade. This field has seen several revolutionary advancements since being introduced by Richard P. Feynman, Nobel laureate, in 1959. The idea of nanotechnology was first proposed by James Clerk Maxwell in 1867. In his vision, microscale machines could manipulate atoms and molecules individually. He referred to them as Maxwell's demons, which are now known as nanorobots. Nano derives from the Greek word "nanos," meaning dwarf. The field of nanotechnology refers to using scientific knowledge to manipulate and control matter mainly at the nanoscale (1–100 nm), utilizing properties and phenomena resulting from size and structure that differ from those of individual atoms and molecules or extrapolating them from larger materials. This field offers the possibility to understand, manipulate, and control materials in ways that were not previously possible, making it an important area of research with many potential applications. One of the most promising applications of nanotechnology is in medicine. Nanomaterials can be designed and engineered to target specific cells or tissues in the body, allowing for more precise drug delivery and treatment. Additionally, nanotechnology-based therapies for infectious diseases have shown potential in preclinical studies. So, in order to qualify as nanomaterials, the materials must meet two conditions: one of their dimensions must be nano, and some of their properties must be nano-specific (Khan et al. 2019; Feynman 2018; Aeran et al. 2015; Tiwari et al. 2012; Schmalz et al. 2017; Kesharwani et al. 2018; Mohamad et al. 2018; Khalaf et al. 2012; Shahbazi et al. 2022).

Nanomaterials

Nanostructure and Synthesis

Many nanostructured materials have been introduced in past decades. Based on their overall shape, these materials can be classified into zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D).

0D nanomaterials are regarded as the forerunners. Considering their extremely small size and high surface-to-volume ratio, 0D nanomaterials have more active edge sites per unit mass. Most 0D nanomaterials are spherical or quasi-spherical. Nanomaterials can be converted into zero-dimensional structures to give them distinct properties that differ from those of higher-dimensional materials. As a result of their unique properties, 0D nanomaterials have wide application possibilities in nanomedicine, cosmetics, bioelectronics, biosensors, and biochips. These include optical stability, wavelength-dependent photoluminescence, chemical inertness, cellular permeability, and biocompatibility (Liang et al. 2014; Sondhi et al. 2019; Yao et al. 2018; Wang et al. 2020).

In the decade following the discovery of 0D fullerenes, 1D carbon nanotubes and 2D graphene sheets have been developed for various applications due to their excellent material characteristics. 1D nanomaterials have only one nanoscale dimension, which can be used in different structures and morphologies. Ribbons, tubes, and rods are examples of 1D nanoparticles. Materials classified as 2D are those with a thickness of only one or a few atomic layers, and electrons can move freely in the other two non-nanoscale dimensions. In 2D nanomaterials, the thickness-to-size ratio is high, resulting in a freestanding sheetlike structure. Because of their excellent physicochemical properties, some 2D nanomaterials, including graphene and graphene derivatives, black phosphorus, and transition metal dichalcogenides, have been used to replace or restore damaged tissue (Erol et al. 2018; Castillo-Blas et al. 2020; Cheng et al. 2020; Zheng et al. 2021).

The term “3D nanomaterials” refers to materials that are not constrained to a single dimension at the nanoscale. This class has many types of nanoparticles, including bulk powders, nanoparticle dispersions, nanowire bundles, and multilayer nanoparticles. A nanoparticle (NP) is not a simple molecule, and it is composed of three layers: (1) surface layer: functionalization of this layer can be achieved using small molecules, metal ions, surfactants, and polymers; (2) shell layer: chemically, the shell layer is distinct from the core in all aspects; (3) core: an NP’s core refers to its central portion, usually the entire NP (Khan et al. 2019; Tiwari et al. 2012; Shin et al. 2016).

The synthesis of nanomaterials involves various methods such as chemical precipitation, sol-gel, hydrothermal, and sonochemical methods. These methods can be used to control nanomaterials’ size, shape, and composition. Recently, green synthesis methods using plant extracts and microorganisms have gained significant attention due to their eco-friendliness and low cost (Banakar et al. 2022a; Kumar and Gangawane 2022). Nanomaterials exhibit unique properties that differ from their bulk counterparts. These properties include high surface area, size-dependent optical and electronic properties, and quantum confinement effects. These properties make nanomaterials useful in various applications such as sensing, catalysis, energy storage, and biomedical applications (Shaik et al. 2023; Baig et al. 2021).

Types of Nanomaterials

Various types of nanomaterials allow them to be used in various ways (Baig et al. 2021). The nanomaterials are of different types based on their morphology, size, properties, and constituents: carbon-based nanomaterials, metal nanoparticles, semiconductor nanomaterials, polymeric nanomaterials, and lipid-based nanomaterials. In the following, we will discuss some of their types:

1. Carbon nanotubes (CNTs): CNTs are cylindrical structures of carbon atoms arranged in a hexagonal lattice. These structures have exceptional mechanical, electrical, and thermal properties, making them ideal for various applications, including energy storage, electronics, and biomedicine (Dervishi et al. 2009).
2. Graphene: Graphene is a two-dimensional material composed of a single layer of carbon atoms arranged in a hexagonal lattice. It has excellent mechanical, electrical, and thermal properties, making it ideal for electronic devices, energy storage, and sensing applications (Zhao and Qiu 2017).
3. Metal nanoparticles: Metal nanoparticles typically comprise gold, silver, or platinum and have unique optical and catalytic properties. They are used in various applications, including biomedical imaging, drug delivery, and catalysis (Sajid and Płotka-Wasylka 2020).
4. Quantum dots (QDs): QDs are semiconductor particles with a diameter of fewer than 10 nm. They exhibit unique electronic and optical properties, making them ideal for applications such as solar cells, LEDs, and biological imaging (Lim et al. 2015).

Nanotechnology Applications

Daily life applications of nanotechnology are numerous and diverse. Including nanoparticles in daily food, dietary supplements, and sprays used to coat, clean, and impregnate products is common. Nanotubes are increasingly being applied in computer devices instead of silicon chips. Nanoclays and zeolites are used to improve fertilizers in the soil nutrient broth and soil fertility restoration (Schmalz et al. 2017; Malik et al. 2023). In the following, some applications of nanomaterials are mentioned:

1. Biomedical applications: Nanomaterials have great potential in biomedicine due to their small size and unique properties. They can be used for drug delivery, cancer therapy, antimicrobial and antiviral materials, and imaging (Banakar et al. 2022a, b, c; Singh and Patel 2022).
2. Energy storage: Nanomaterials have been shown to enhance the performance of energy storage devices such as batteries and supercapacitors (Pomerantseva et al. 2019).
3. Environmental applications: Nanomaterials have the potential to be used for environmental applications such as water purification and air filtration (Kaphle et al. 2018).
4. Electronics: Nanomaterials are being used to develop electronic devices such as sensors, transistors, and memory devices (Choi et al. 2016).
5. Catalysis: Nanomaterials are being used as catalysts in a wide range of chemical reactions, including producing chemicals, fuels, and pharmaceuticals (Polshettiwar and Varma 2010).

Nanomedicine

Nanomedicine, an exciting field that operates at the molecular-size scale, uses nanotechnologies to develop new methods of diagnosing and treating human diseases. It offers many possibilities, including the seamless integration of biology and technology, the development of personalized medicine to eradicate disease, targeted drug delivery, regenerative medicine, and nanomachinery that can substitute portions of cells. The idea of tiny surgeons who can be swallowed was one of Feynman's wild ideas in his lecture, hinting at nanotechnology's application in medicine. Nanomedicine has become an active area of research and development with the potential to revolutionize disease diagnosis, treatment, and prevention. Researchers are working on developing nanoparticles that can target cancer cells and other diseases and deliver drugs with minimal side effects. During the pandemic in 2019, some research was conducted to analyze nanotechnology to combat Coronavirus, and some results were promising (Feynman 2018; Schmalz et al. 2017; Freitas 2000; Adir et al. 2020; Shi et al. 2017; Mishra 2016; Rahman et al. 2022; Hasanzadeh et al. 2021). Nanomedicine has the potential to transform the healthcare industry, and researchers are continually exploring new possibilities and applications for its use.

Nanodentistry

Dentistry is a new field where nanotechnology is being applied. It allows for treating oral health issues and repairing oral lesions on a nanoscale level. Nanodentistry uses nanomaterials and nanorobots to manipulate matter on a very small scale. The term "nano dentistry" was attributed to R.A. Freitas Jr. in 2000. He envisaged using nanorobots in orthodontics, regenerating teeth with nanomaterials, and robots in dentifrices called dentifrobots. He developed several ideas, some of which are still considered science fiction today. Nanotechnology is expected to have impacts on diagnosis, materials, restorative, and surgery in the field of dentistry (Deyhle et al. 2012). In restorative dentistry, nanorobots can be used in cavity preparation, restoration, and even dentition renaturalization, providing greater accuracy and precision in dental procedures. In orthodontics, nano dentistry offers possibilities for developing advanced orthodontic materials. Nanodentistry also has the potential to revolutionize periodontics, as nanotechnology can be used to develop new treatments for periodontal diseases. With its many applications and potential benefits, nano dentistry is an area of active research and development in dentistry (Chandra Mouli et al. 2012; Kasimoglu et al. 2020). Nanotechnology has a variety of applications in dentistry, some of which are mentioned in Table 1.

Nanotechnology's application to cancer has attracted considerable attention over the past few years. Compared to current clinical diagnostic devices, nanotechnology presents unparalleled promise for cancer diagnosis because nanotechnology allows multiple levels of diagnosis, ranging from tissue imaging to molecular imaging. It is crucial to use imaging to diagnose cancer, stage it, and evaluate treatment outcomes.

Table 1 Applications of nanotechnology in disciplines of dentistry

Discipline	Applications of nanotechnology
Restorative dentistry	Development of biocompatible and non-toxic dental restorative materials such as GIC, and dental composite. In particular, incorporating nanoparticles into resin-based restorative materials has improved their mechanical properties, such as compressive and flexural strength and wear resistance
Oral and maxillofacial surgery (OMS)	Use of nanomaterials for bone graft materials, dental implants, and nanoparticles in existing therapeutic modalities. Nanoparticles have also been shown to enhance the effectiveness of drugs by improving drug delivery and targeting specific cells or tissues in OMS. Nanoparticles have been shown to enhance bone growth and to promote wound healing in OMS. The use of nanotechnology in diagnostic imaging, medicine and surgery has revolutionized the field of OMS
Prosthodontics	Development of nanocomposites and nanocomposite coatings for dental prostheses to improve their mechanical properties and reduce the risk of bacterial colonization. Also, nanoparticles such as bioglass, zirconia, and glass ceramics have been incorporated into types of cement to improve their properties
Periodontics	Use of nanofibers for periodontal regeneration and tissue engineering. Use of antimicrobial substances such as silver nanoparticles, chlorhexidine nanoparticles
Endodontics	Developing nanomaterials that can be used in root canal treatments, such as nanoparticles that can help disinfect the root canal system. Use of nanocarriers for delivery of antimicrobial agents to treat endodontic infections
Orthodontics	Using nanomaterials to create orthodontic wires and brackets that are stronger, more biocompatible, and corrosion-resistant. Use of nanorobots for complete orthodontic realignment in a single visit
Pediatric dentistry	Use nanoparticles in existing therapeutic modalities, such as local drug delivery agents and restorative materials

As the number of nanomaterials used in biomedical imaging continues to rise, a wide range of nanomaterials is becoming available, including NIR-absorbing carbon, metal, quantum dots-based nanostructures, magnetic particles, and composites based on upconversion. Detection of biomarkers of tumor cells with nanotechnology allows earlier detection and improves the sensitivity of cancer tests (Adeola et al. 2020).

Several applications of nanotechnology have been discovered in dentoalveolar surgery. Nanotechnology can improve wound healing, regenerate bones, and stimulate angiogenesis in dentoalveolar surgeries. It can also decrease the risk of infection at the surgery site. Cell surgery will be possible using nanoscale instruments like nanotweezers and nanoneedles. An investigation is underway to develop suture needles incorporating nanosized stainless steel crystals. These needles may be used to perform incisions at the cellular level (Aeran et al. 2015).

For tissue regeneration and development, it is essential to promote early angiogenesis. The vascular network provides oxygen and nutrients, which facilitate wound healing. For example, early angiogenesis accelerates osteoprogenitor cells' migration, differentiation, and bone formation in a bone defect. By endocytosing nanoparticles via clathrin and caveolae, nanoparticles can alter cellular behavior and facilitate angiogenesis. During the endothelialization process, nanofibers, electrospun scaffolds, or other mesoporous structure scaffolds mimic blood vessels' natural extracellular matrix (ECM). Also, nanomaterials can be used to improve pro-angiogenic factor delivery sensitivity and target (Liu et al. 2020).

Nanotechnology in Dental Materials

Nanotechnology has revolutionized the field of dental materials, with vast applications ranging from diagnostics to treatment options (Jandt and Watts 2020). Nanocomposites, nanoparticles, antimicrobial nanomaterials, and bio-mineralization systems are the most frequently reported dental nanomaterials (Fig. 1). This reflects the growing interest in nanotechnology applied to dentistry, as it allows for developing materials that improve oral prevention and treatment (Jandt and Watts 2020; Padovani et al. 2015). Using nanomaterials in dentistry has enabled the development of new preventive strategies and materials, such as nano-antibacterials and nano-coatings, that reduce bacterial adhesion (Banakar et al. 2022b; Jandt and Watts 2020). Composite resins are one of the most common restorative materials in dentistry. These materials are divided based on their particle and fillers size. These composites were able to improve their properties over time by using nanotechnology. Table 2 shows the composite types based on particle size (Mikhail et al. 2014; Sultan et al. 2015).

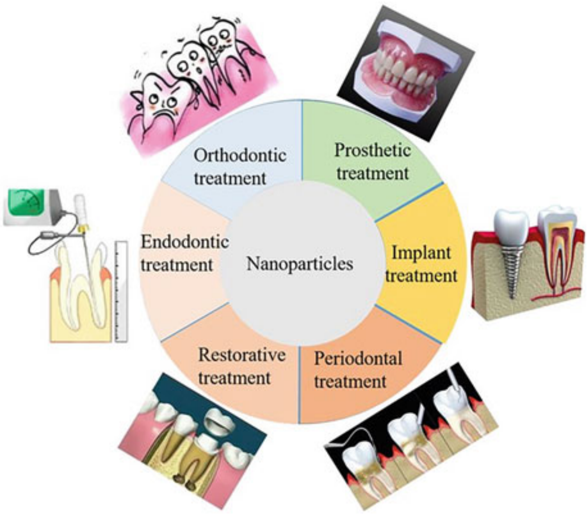

Fig. 1 The application of nanoparticles in dentistry (Liu et al. 2021)

Table 2 The classification of dental composites according to filler size

Type of composite	Characteristics	Filler size	Positive points	Negative points
Microhybrid composite	Contains micro-sized particles (0.04–3.0 μm)	0.04–3.0 μm	Good mechanical properties, polishability, and esthetics	Limited wear resistance and increased shrinkage
Nanohybrid composite	Contains nanosized particles (<100 nm) and micro-sized particles	<100 nm and 0.6–1.4 μm	Improved strength, wear resistance, and polishability compared to microhybrid composites	More technique-sensitive, increased polymerization shrinkage
Nanofilled composite	Contains primarily nano-sized particles (<100 nm)	<100 nm	High polishability, wear resistance, and good esthetics	More expensive, lower filler loading than microhybrid composites
Nanoceramic composite	Contains ceramic particles in the nanometer range	<100 nm	High strength and durability, good esthetics	Limited clinical data and long-term performance
Microfilled composite	Contains micro-sized particles (0.02–0.4 μm)	0.02–0.4 μm	Excellent esthetics and polishability	Low mechanical properties and high wear rates
Packable composite	Contains micro-sized particles (0.04–5.0 μm)	0.04–5.0 μm	Good handling and adaptation to cavity walls	Limited ability to achieve high surface polish

Additionally, nanotechnology has enabled the development of dental implants with improved osseointegration, increased mechanical strength, and reduced inflammatory response (Padovani et al. 2015). Furthermore, nanotechnology has been applied to regenerative dentistry, allowing for the development of nanofibrous scaffolds that facilitate cell adhesion and proliferation. Nanotechnology has also enabled the development of aesthetic and conservative dental materials that allow for better color matching and minimal tooth reduction during dental restoration procedures. It is possible to restore teeth using different nanomaterials. Several new nanomaterial technologies have been introduced to dentistry in recent years, such as composite materials, nano impressions, and nanoceramics (Padovani et al. 2015; Maloo et al. 2022).

Dental Materials with Nanofillers

Nanofillers are a crucial component of dental biomaterials at the nanoscale level. In the past few years, nanotechnology has gained increasing popularity in dentistry and is making a significant impact with nanofillers (NF) in dental materials. NF aims to improve dental materials' physical and mechanical properties by adding small particles with a diameter of fewer than 100 nm. Several dental materials, including composites, cement, and adhesives, have been used to restore and replace teeth for several years. However, these materials have shortcomings, such as low wear resistance and poor mechanical properties. To overcome these limitations, NF is added to dental materials. Nanofilled resin composite materials have been shown to exhibit improved mechanical properties, such as strength, hardness, abrasive wear, water sorption, and solubility, which are critical for their clinical performance (Mikhail et al. 2014; Alzraikat et al. 2018).

Nanomedicines are biologic and physicochemical entities with specific properties that make them superior to conventional dental materials in overcoming side effects. Nanomaterials mimic the features of host tissues, yet dentists are not familiar with such features. Adding NFs increases dental materials' strength, toughness, wear resistance, and durability. Incorporating nanoparticles in dental implant coating materials have also shown promise in improving dental wear resistance and bone grafting. Various types of nanoparticles, such as Ag, ZrO_2, and TiO_2, have been coated on dental implant surfaces to create novel methods for treating many dental diseases (Moradpoor et al. 2021). Moreover, nanofillers enhance the aesthetics of dental materials by increasing their translucency and reducing their opacity. Several metal and polymer-based nanomaterials are used in dental adhesives, restoratives, acrylic resins, periodontics, tissue engineering, endodontics, and implantology (Maloo et al. 2022; Karthikeyan et al. 2019; Uno et al. 2013; Foong et al. 2020).

Nanofibers can be classified into different material-based categories, such as organic, inorganic, composite, and carbon-based. Carbon and polymer nanofibers are examples of nanofibers used in structural carbon fiber-reinforced polymer (CFRP) matrix composites. These composites have high strength and stiffness and are used in aerospace and other high-performance applications. Polymer nanofiber-reinforced nanocomposites are another example of nanofibers used in medical applications, where they can improve mechanical properties, such as strength and toughness, of the implant materials. Additionally, polymer/CNF composite nanofibers can be used to modify the thermosetting polymer, improving its mechanical and thermal properties (Nasrollahzadeh et al. 2019; Rakhi et al. 2023). Types of nanoflares and their structure are shown in Fig. 2.

Benefits and Drawbacks of Nanofillers in Dental Materials

There are several benefits to using NFs in dental materials. First, NFs increase the mechanical properties of dental materials, making them stronger, tougher, and more durable. Second, they enhance the aesthetics of dental materials by improving their translucency and reducing their opacity. Third, they can reduce the polymerization shrinkage of dental composites, which is a significant cause of marginal gaps and secondary caries. Fourth, they can improve the bonding strength of dental adhesives,

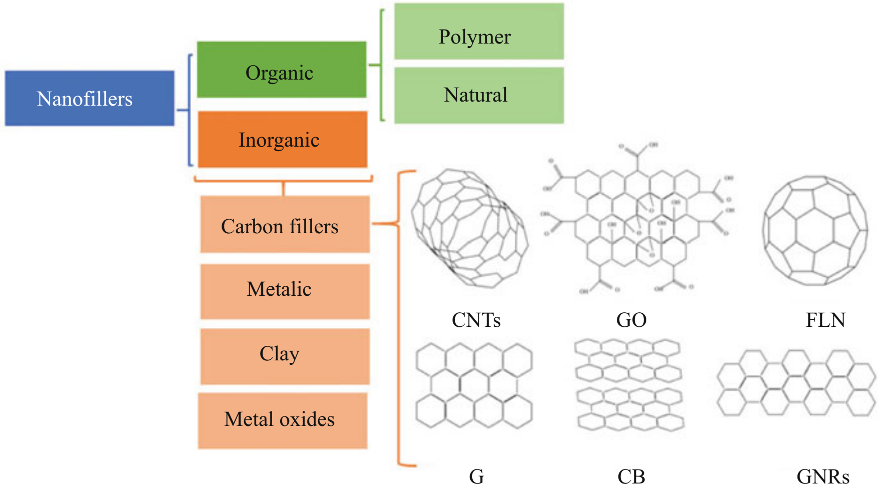

Fig. 2 Various types of nanofillers (Ehsani et al. 2021)

which is essential for the success of adhesive restorations (Mikhail et al. 2014; Alzraikat et al. 2018).

Their large surface area ensures a high level of performance. When nanoparticles loaded with an antimicrobial agent are incorporated in resin composites, they can present antimicrobial, antiviral, and antifungal properties that prevent the formation of biofilms. Restorative dentistry makes use of them extensively to enhance dental material's mechanical properties. Dentin bonds better with biomaterials when they are present. The cracks are prevented from propagating and white spots are prevented. Restorations made from porcelain are more fracture-resistant (Jandt and Watts 2020; Uno et al. 2013; Foong et al. 2020; Kasraei et al. 2014; Vasiliu et al. 2021).

Regarding endodontics, there are many examples of nanotechnology in action in endodontic sealers, including bioglass, zirconia, and glass ceramics. A nanoparticle adhesive is faster in setting, dimensionally stable, better at responding to nano-irregularities, and able to chemically connect to tooth tissues (Utneja et al. 2015). An intracanal medication containing calcium hydroxide and silver nanoparticles suppressed *Enterococcus faecalis* growth, both short-standing and long-lasting (Mozayeni et al. 2014). Nanodiamond particles were also incorporated into gutta-percha to improve its performance. Digital radiography and microcomputed tomography showed that diamond-impregnated gutta-percha performed better in mechanical, chemical, and biocompatibility than traditional gutta-percha. Because nano-gutta-percha adapts well to canal walls and produces minimal voids, it has the potential as an enhanced endodontic filler (Lee et al. 2017; Lee et al. 2015).

NFs can also enhance the aesthetics of dental restorations when incorporated into dental materials. To increase translucency, dental composites can be improved with NFs, which is crucial to achieving a natural-looking appearance that mimics natural teeth. In several studies, NFs have been shown to increase dental composite translucency and reduce opacity. Dental materials incorporating NFs may have a detrimental effect on biocompatibility. Inflammation, cytotoxicity, and genotoxicity can occur when NFs interact with the oral environment. Research has been conducted on the biocompatibility of dental materials that contain NFs, but the results have been mixed (Brantseva et al. 2016; Tuteja et al. 2007; Dorigato et al. 2010). NFs have been included in dental composites, types of cement, and adhesives for over two decades, and studies have evaluated the benefits and drawbacks of doing so. In addition to adding different properties to nanocomposite materials, these NFs will enhance their mechanical, thermal, flame retardant, and water absorption properties and maintain their optimal density. Due to their superior properties and larger surface area, nanocomposites are widely used in many industries (Khalil et al. 2019; Li et al. 2021).

The best adhesion properties can be achieved only through uniform dispersion of NFs and improved filler–matrix interaction. By using the dispersion technique and appropriately modifying the surfaces of NFs, it is possible to control dispersion. Several methods for dispersing NF were evaluated, including in situ polymerization and ultrasonic mixing. Additionally, the best results require exfoliation or intercalation of NFs, generally achieved by optimizing filler loading. This results in a stronger adhesive with reduced residual stress, improving cohesive strength and modulus (Dorigato et al. 2010; Guchait et al. 2022; Jagadeesh et al. 2021). An increase in filler content results in the formation of aggregates, which worsen the joint's strength by acting as stress concentration points. The modification of NFs affects the curing kinetics, rheology, and adhesion properties of the adhesives by improving compatibility between the NFs and the matrix. In addition to improving adhesion, NFs also improve wetting properties. Based on the geometry, surface modification, and flexibility of the nanocomposite, fracture toughening of the adhesive joint can occur by various mechanisms. Nanocomposite adhesives generally toughen by bridging cracks and reducing crack propagation by crack deviation. Integrating NFs increases the adhesion strength, thus enhancing the shear resistance of the adhesive (Brantseva et al. 2016; Dorigato et al. 2010; Li et al. 2021; Guchait et al. 2022; Jagadeesh et al. 2021).

Among the high-performance thermoplastic polymers within the polyaryl-ether-ketone (PAEK) family, polyether-ether-ketone (PEEK) and polyether-ketone-ketone (PEKK) are both included. PEEK is a semicrystalline organic polymer developed for orthopedic and dental implants with a highly stable chemical structure. Ti-based metallic implants commonly exhibit stress shielding due to their high elastic modulus (3–4 GPa) compared to PEEK. An elastic modulus of 18 GPa, like that of human bone, can be achieved by adding reinforcing NFs to PEEK. Aside from being readily fabricated by conventional plastic processing techniques, PEEK can be readily sterilized, making use of ethylene oxide gas, steam, and radiation without adversely affecting its mechanical characteristics or biocompatibility (Abhay et al. 2021; Alqurashi et al. 2021; Yin et al. 2022). Taymour et al. evaluated PEEK/BG (bioglass) and PEEK/FT (forsterite) nanocomposites and determined them to have different microhardness, elastic modulus, and flexural strength. The rough PEEK/FT nanocomposites, when immersed in SBF for 28 days, exhibit enhanced bioactivity due to their rough structure and nano-FT crystals. This research opens the possibility of PEEK-based nanocomposite being used in orthopedic and dental implants as a viable alternative (Taymour et al. 2022). Polymerization stresses are distributed differently in adhesion systems in the presence of silicon nanoparticle fillers, resulting in improved mechanical properties and elastic modulus. According to this study, the mechanical properties of adhesives depended on the amount of NFs added to Bis-GMA, TEGDMA, or HEMA adhesive systems (Leitune et al. 2013).

Researchers have developed new drug delivery systems for treating periodontitis using nanoparticles loaded with triclosan or tetracycline. Drug delivery, especially to smaller particles of less than 100 nm, can be made easier with chemically stable nonionic vesicles known as "niosomes" (Verma et al. 2018). Root canal procedures can benefit from chlorhexidine-containing nanoparticles. Bacteria may be sustainedly inhibited in the root canal system due to their size and rate of release (Haseeb et al. 2016; Abdelmonem et al. 2019). Furthermore, a chlorhexidine coating with varied nanoparticle additions was tested for soft denture liners and obturators. This study involved chlorhexidine combined with sodium triphosphate, trimetaphosphate, and triphosphate. Using these coatings could promote oral health, extend the lifespan of dental prosthetics, and save patients money (Quiram et al. 2018).

To enhance the antimicrobial and structural properties of PMMA denture foundations, TiO2 nanoparticles were added. The structural and chemical features of *Candida* species were significantly changed according to FTIR, SEM, and antimicrobial efficiency tests. Heat-cured PMMA modified with nano zirconium oxide was also examined. Because of their superior dispersion qualities, decreased aggregation potential, and biocompatibility with the organic polymer, zirconium oxide nanoparticles enhanced the denture base's hardness, flexibility, and fracture toughness. As well as increasing the transverse strength, nano zirconium was employed during the building process to strengthen denture bases (Ahmed and Ebrahim 2014; Gad et al. 2016).

In addition, resin nanoceramic CAD/CAM blocks showed improved tribological properties (Chen et al. 2014). A 3-year follow-up study showed an 83.1% survival rate for CAD/CAM partial crowns for posterior teeth undergoing endodontic treatment. Resin nanoceramic material surfaces may have been pretreated to affect debonding, the most common failure pattern (Zhang et al. 2022). Resin nanoceramic figures are suggested to be an alternative to posterior crowns if debonding issues can be solved. Even though glass ceramic crowns and resin nanoceramic crowns exhibit distinct damage modes, both potentially cause bulk fractures (Ferruzzi et al. 2019).

The size of nanofiller particles has consistently been cited as an essential factor in the process. As a result of large particles agglomerating, the mechanical properties of the interface can be degraded. Modified material properties are also greatly affected by the type of nanofiller. FTIR spectroscopy confirmed that the nano-cHAp filler's uniform distribution in the adhesive matrix and its interaction with the filler's molecular groups contributed to a change in molecular bonding, resulting in a significant improvement in the material's mechanical properties (Taymour et al. 2022).

However, using NFs in dental materials also has some drawbacks. One of the main concerns is the potential toxicity of these particles, as they are so small that they may enter the bloodstream and cause harm to the body. Next, incorporating them in dental materials can affect the handling properties of these materials, making them more challenging to manipulate. Second, the high surface area of NFs can increase the reactivity of dental materials with the oral environment, leading to faster degradation and reduced longevity. Third, using NFS in dental materials can increase their cost, making them less accessible to patients who cannot afford expensive dental treatments (Mikhail et al. 2014).

Future Trends in Nanofillers

The use of NFs in dental materials is expected to grow. One of the significant trends in their use is the development of new nanomaterials with superior properties. For example, researchers are exploring graphene, a two-dimensional material, as a filler in dental composites. Graphene has excellent mechanical, electrical, and thermal properties, making it a promising filler for dental materials. Another trend in the use of NFs is the development of multifunctional materials. Multifunctional materials are designed to have multiple functions, such as antimicrobial, remineralization, and drug delivery properties. For example, researchers have developed dental materials that contain silver nanoparticles, which have antimicrobial properties and can prevent secondary caries. Moreover, researchers are exploring using NFS to deliver drugs, such as fluoride and antibiotics, to the oral cavity, which can prevent or treat oral diseases.

Medicinal products likely contain silver nanoparticles in composites. These new nanomaterials should be evaluated in light of their potential benefits as well as their potential hazards. Enhanced pro-inflammatory responses and oxidative stress may result from silver nanoparticles directly incorporated into resin-based composites. Often, salivary mucous particles may be trapped in the epithelium, causing local hypersensitivity reactions to the salivary components. Health and safety are two key aspects of nanotechnology that "go green." Environmental, public, and occupational health risks should be carefully weighed against the potential benefits of green nanotechnology. It will positively impact the environment, society, and health and reduce costs. A recent development in nanomaterials and nanotechnology is promising for regenerating a full periodontal apparatus, including dentine, cementum, periodontal ligaments, and bone. Animals can be stimulated by creating host tissues using tissue engineering scaffolds and triads studded with nanoparticles. Because they are low toxicity and antibacterial, as well as improve protein-surface interactions, they make ideal dental materials. A variety of new and superior biomaterials could be created using these materials, which dentists are eager to develop. Dental care may be improved with advances in nanotechnology and improvements to conventional treatment methods (Maloo et al. 2022; Karthikeyan et al. 2019; Umapathy et al. 2022).

Conclusion

In conclusion, using NFs in dental materials has many benefits, such as improving mechanical properties, enhancing aesthetics, and reducing the polymerization shrinkage of dental materials. However, using nanofillers also has some drawbacks, such as affecting the handling properties, increasing the reactivity, and raising the cost of dental materials. Future trends in using NFs include developing new nanomaterials with superior properties and developing multifunctional materials with antimicrobial, remineralization, and drug delivery properties.

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