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Nanoparticles and Their Application in Prosthetic Dentistry

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ABSTRACT

In recent years, nanoparticles produced with nanotechnology have been widely used in many fields of medicine and dentistry such as prosthetic dental treatment. The advanced properties of nanoparticles such as biocompatibility, durability, solubility, large surface area, high stability, and thermal conductivity facilitate the development of dental materials. Compared to the traditional materials used, they can offer useful features, such as better diagnosis, treatment plans, improvement, and protection of oral health. Therefore, a better understanding of nanotechnology and nanoparticles is essential to appreciate how these materials can be utilised in our daily practice. This review provides an overview of nanoparticles and their applications in dentistry.

Keywords: Nanoparticles, nanomaterials, prosthodontics, denture bases, implantology.

1. INTRODUCTION

The term "nano" describes the research and development of science at the atomic or molecular level, leading to fields such as nanotechnology or nanoscience (1). Nanotechnology is defined as the manipulation of matter in sizes ranging from 1 to 100 nanometers (nm), while a nm is a unit of billionth (10-9 meters) meter in length, denoting dimensions of a matter at the atomic scale (2). Nanomaterials are defined as materials consisting of 50 % or more particles having a size between 1nm-100nm by The European Commission (3).

Nanoparticles can have different morphologies such as prisms, rods, cubes, spheres, and different structures and forms such as nanocrystals, nanocoatings, nanotubes, and nanofibers (4). Nanotechnology and nanoparticles can be used in various medical fields such as pharmacological research, clinical diagnosis, support of the immune system, cryogenic storage of biological tissues, detection of proteins, investigation of DNA structure, and tissue engineering (1). The change in the mechanical, optical, chemical, and electrical characteristics of nanoparticles has led to developments in nanomaterials and biotechnology, and it has increased their use in various industrial sectors, medicine, and dentistry (2,5).

Most of the research in dentistry is conducted to develop materials that are biocompatible and can withstand the hard conditions of the oral environment. The use of nanoparticles in dentistry is increasing rapidly due to physicochemical and biological characteristics such as biocompatibility, durability, solubility, large surface area, high stability, and thermal conductivity. However, some nanoparticles have disadvantages and limitations such as toxicity and limited availability besides their numerous advantages (4).

Although there are many synthesis methods such as mechanochemical processing, sol-gel, thermal decomposition, ionic-liquid route, hydrothermal synthesis, spray pyrolysis, and emulsion precipitation in the synthesis of nanoparticles, the most frequently used methods in dentistry are sol-gel method and hydrothermal synthesis method (4,6,7).

Sol-Gel Synthesis Method: It is difficult to control the structure during the production of nanoparticles. In the sol-gel synthesis method, nanoparticles can be obtained in desired sizes homogeneously and in different structures such as nanofibers, nanowires, nanotubes, flakes, flowers, and stars (8).

Sol is defined as a stable colloidal suspension of solid particles in a liquid, while gel is defined as a stably expanding, porous, three-dimensional, and semi-solid mesh. Particle characteristics and phase structure can be changed by using the two most common precursor groups: metal alkoxides and

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metallic salts. The most common nanoparticles for dental materials are metal oxides (7,9,10).

Nanoparticles such as silica (SiO_2) and zirconium (ZrO_2) produced by the sol-gel method are used in many fields such as nanofill composites, glass ionomers, and adhesives (11). Although the advantages of the sol-gel synthesis method can be counted as providing high purity and homogeneous dispersion nanoparticle synthesis, being easy and commercialized, longer synthesis times, and low sintering capacity can be counted as the disadvantages (7). Shukale and Seal (12), successfully synthesized nanocrystalline ZrO_2 nanoparticles which contain 100% tetragonal phase, by the sol-gel method.

Hydrothermal Synthesis Method: The hydrothermal method is an ideal technique to synthesize various nanomaterials with high purity and controlled microstructure (6). It is an advanced technology for the preparation of nanocrystal by a chemical reaction in an aqueous solution under high temperature and pressure. The hydrothermal synthesis method has many advantages such as high purity, various crystal shapes, homogeneous distribution, saving time, and providing controllable size particle synthesis; against these advantages excess equipment and high heat requirement are considered disadvantages (7).

Taguchi et al. (13) synthesized ZrO_2 nanoparticles by hydrothermal method and found that the products synthesized at temperatures above 300°C contained the mixtures of tetragonal and monoclinic phases, while the products synthesized at 200°C showed an amorphous phase. Arantes et al. (14) synthesized $ZrO(NO_3)_2.H_2O$ and $ZrOCl_2.8H_2O$ aqueous solutions by hydrothermal treatment at 110°C for 24 hours and obtained pure nanocrystalline stable monoclinic zirconia colloids.

1.1. Dentistry and Nanoparticles

The use of nanoparticles in dentistry is rapidly increasing due to their physicochemical and biological properties such as biocompatibility, durability, resolution, high stability and thermal conductivity. The use of nanoparticles is promising because they are materials that can help prevent or eliminate oral problems such as dental caries, periodontal disease, peri-implantitis, oral candidiasis, and shorten the treatment period (4). Hydroxyapatite (HA), SiO_2, Carbon (C), Titanium dioxide (TiO_2), and ZrO_2 are some of the nanoparticles used in dentistry (5).

In dentistry, nanotechnology has started with the addition of nanoparticles to filling materials, and nanoparticles are used in the production of bone graft materials, endodontic antimicrobial irrigation agents, sealer materials, remineralization agents, orthodontic wires and brackets, dental implants, dental prosthesis materials, anti-sensitivity and whitening agents, tooth enamel polishing agents, and anti-caries agents (5,15).

1.1.1. Nanoparticles in surgical treatments

Nanotechnology and nanoparticles are used in many areas of surgery such as improving implant surface properties, increasing osteointegration, tissue compatibility and biocompatibility, production of bone grafts, and in the diagnosis and treatment of oral cancers.

1.1.1.1. Use in implant treatments

Dental implants can be coated with various nanoparticles using nanotechnology. The surface of the implant plays a critical role in ensuring biocompatibility and osteointegration in implant supported prostheses, which is the gold standard treatment option for tooth loss. Coating the implants with pharmacological nanoparticles such as nano TiO_2, HA, calcium phosphate ($Ca_3(PO_4)_2$), calcium silicate (Ca_2O_4Si), C and bisphosphonates induces cell differentiation, and proliferation and can provide a suitable environment for early and long-term bone formation by increasing vascularity in cortical bone (16).

Due to its similarity to the inorganic components of bone, nano-HA is the most preferred nanocoating for dental implants. Implants with nano-HA surface showed better osteointegration, bone formation, and better bone-implant interaction (17,18). Yang et al. (19) evaluated the effects of titanium implants coated with nano-HA on osseointegration after 6 and 12 weeks of placement and showed that HA nanoparticles increased osteointegration.

Copper, bismuth and silver (Ag) nanoparticles with antibacterial properties are used for the prevention and treatment of periimplantitis. TiO_2 nanoparticles significantly reduce microbial adhesion, roughness, and chemical weathering on implants, significantly reducing the number of bacteria attached to the implant surface (5).

1.1.1.2. Use in graft materials

Bone is a natural nanostructure composed of organic compounds reinforced with inorganic structure. Bone grafts are materials that mimic natural bone. Nanocrystals containing calcium as in bones and collagen particles mimicking soft tissues around bones can be used as bone-like nanoproducts. The mixture of nanocrystalline calcium sulfate particles and calcium sulfate hemihydrate powder is one of the graft materials produced with nanotechnology (20).

1.1.1.3. Use in diagnosis and treatment of oral cancers

The very small size of the nanoparticles allows them to pass through the kidneys, be carried into the tumors through the vessels, and collected in the tumors. Therefore, in cancer treatment, multifunctional nanoparticles like cadmium selenide can be produced that will detect, image, and treat tumors (21).

Magnetic, colloidal gold, and ceramic nanoparticles have been used in new and effective drug systems developed with nonatechnology to eliminate the disadvantages of existing cancer treatment techniques (22).

1.1.2. Nanoparticules in endodontic treatments

In endodontic treatments, nanoparticles are used as antimicrobial agents to reduce the disadvantages of traditional antibacterial agents. Nanoparticles can also be used by adding them to sealers, canal filling material, intracanal medicaments and irrigation solutions (23).

1.1.2.1. Use in irrigation solutions

Nanoparticles can be added to traditional irrigation solutions such as chlorhexidine (CHX), sodium hypochlorite (NaOCl), and chitosan in order to reduce their cytotoxic effects on the surrounding bone and soft tissues (23). Ag and chitosan nanoparticles are frequently used because of their rapid bactericidal effect, biocompatibility, low toxicity, and long-term antibacterial activity (23,24) It has been shown that Ag nanoparticles provide superior antibacterial effect compared to 2.5% NaOCl (25).

1.1.2.2. Use in intra-canal medications

Intracanal medicaments function as anti-inflammatory and antibacterial agents that can be used between appointments (23). While calcium hydroxide paste is commonly used, the addition of Ag nanoparticles (20 nm) to calcium hydroxide can increase the antibacterial effect of the material (25).

1.1.2.3. Use in canal filling materials

Gutta percha, Ag tips, and resilon are commonly used obturation materials for root canal filling. The addition of bismuth oxide, niobium oxide, and ZrO2 nanoparticles into the canal filling materials provides a radiopacifying effect and facilitates treatment follow-up on the radiograph (7).

Ca2O4Si nanoparticles ranging in size from 80 to 100 nm are viscous, antibacterial stimulating bone formation, and are used in the apical third of root canals (26). To improve the properties of endodontic pastes, nanoparticles such as chitosan and zinc oxide (ZnO) can be used to prevent bacterial penetration (4,27).

1.1.3. Nanoparticles In Restorative Treatments

Nanotechnologies can be used for the production of dental composites (nano-composites), glass ionomer cements (nano-ionomers), and materials that regenerate dental tissues.

Ultra-dispersed supramolecular nanoparticles with sizes between 10 micrometer (µm) and 1000 µm can prevent the caries formation process by providing remineralization of the teeth by adding them to toothpaste and mouthwash (28).

1.1.3.1. Use in glass ionomer cements

Conventional and resin-modified glass ionomer cements have disadvantages such as poor aesthetics, mechanical properties, and bond strength, as well as beneficial properties such as releasing fluoride and remineralizing tooth structure in the oral environment. Chitosan, HA, fluorapatite, TiO2, SiO2, and ZrO2 nanoparticles can be added to glass ionomer in order to improve its aesthetic properties (29). Resin-modified glass ionomers containing fluoroaluminosilicate nanoparticles are widely used in clinical practice. In a new nanomaterial, 15% SiO2 nanofillers in 40 nm size were added to the ionomer, and better wear resistance and a reduction in curing time were observed (30). The addition of nano-HA (100–150 nm) to resin-modified glass ionomers increased the bond strength to tooth structure (31).

Kumar et al. (32) showed that the addition of 10% by weight chitosan nanoparticles to the glass ionomer cement increased the resistance of the material and the fluoride release, while İbrahim et al. (33) showed that the addition of TiO2 nanoparticles showed antimicrobial activity with biofilm inhibition and improved some physical properties.

1.1.3.2. Use in dental composites

The use of nanoparticles has increased to improve the physical and aesthetic properties of dental composites and to overcome problems such as polymerization shrinkage, wear resistance, and microhardness.

The most widely used resin nanocomposites are nano-hybrid and nano-filled composites containing fillers in varying proportions (1-100 nm, 20-600 nm) (2,29). Nanofillers mainly contain particles of 1 to 100 nm in size, while nano-hybrids consist of larger particles ranging from 0.4 to 5 µm. Resin-based composites contain glass fillers of barium, zirconium, strontium, or ytterbium. These amorphous particles are usually 400 nm-1µm or larger in size (15,34).

The addition of SiO2 nanoparticles into composite materials increases wear resistance in posterior applications, while SiO2-HA-based nanoparticles relieve dental sensitivity and reduce enamel decalcification (5,35).

1.1.4. Nanoparticles in orthodontic treatments

Roughness, surface free energy, and friction force properties play an important role in orthodontic brackets and archwires. Nanoparticles can be added to the materials in order to improve the mechanical and physical properties of the materials used in orthodontics (1).

Katz et al. (36) reported that orthodontic braces coated with tungsten disulfide nanoparticles reduce the friction force that occurs during orthodontic movements. Cao et al. (37) showed that brackets coated with nitrogen-doped TiO2 nanoparticles were effective in preventing enamel demineralization and gingivitis in patients.

1.1.5. Nanoparticles in prothetic treatments

Nanotechnology is able to develop newer materials with better properties in prosthetic treatments. Nanoparticles such as SiO_2, TiO_2, Ag, and ZrO_2 are used to improve the properties of materials such as resin-containing denture base materials, dental composites, dental impression materials, bonding cements, tissue shapers, dental implants, dental ceramics, and maxillofacial prostheses (5).

1.1.5.1. Use in acrylic resins

Due to its biocompatibility, aesthetics, and stability in the oral environment, ease of repair, tasteless and odorless, high polishability, low cost, and removable dentures are generally made with traditional heat-polymerized polymethylmethacrylate (PMMA) material. However, it has poor mechanical properties such as low bending and impact strength, fracture and fatigue resistance, and insufficient surface hardness, allowing microbial adhesion.

In order to improve the physicochemical properties of the material, zirconium oxide, TiO_2, aluminum, and SiO_2 nanoparticles are added to PMMA. With the addition of ZrO_2 nanoparticles, the dimensional accuracy and tensile strength of the material can be increased significantly, and it can also reduce the adhesion of candida to the surface. However, as the nano-ZrO_2 concentration increases, the translucency of PMMA may decrease (4,38).

Gad et al. (39,40), in their studies, achieved an increase in the bending strength of the denture base in repairs made by adding different sizes and different amounts of nano-ZrO_2 into auto-polymerizing acrylic. In Ashour and Ebrahim's study (41), it has been shown that the addition of 5-15 nm ZrO_2 nanoparticles to PMMA increases its mechanical properties.

TiO_2, ZnO, and Ag nanoparticles can be added to PMMA due to their antimicrobial properties and prevent prosthetic stomatitis (4,42–44). Karci et al. (45) showed that SiO_2 nanoparticle groups had lower flexural strength compared to TiO_2 and aluminum nanoparticle-added groups.

The addition of C nanoparticles to heat-polymerized acrylic reduces polymerization shrinkage and improves mechanical properties. Cooper et al. (46) showed that the addition of a small number of C nanotubes will significantly increase the impact strength of PMMA.

1.1.5.2. Use in dental composites

Synthetic resins are widely used because they are insoluble, aesthetic, insensitive to dehydration, easy to manipulate, and inexpensive. Nano-fillers of 1-100 nm are added to the resin matrix to produce nanocomposites. There are two types of nanoparticles used; nanomers and nanoclusters (47). The nanomers are monodispersed, and non-clustered SiO_2 particles. Nanocluster fillers are 2-20 nm in size (47,48).

Nanocomposites can be divided into subgroups as nanofill composites, nanohybrid composites, TiO_2 added resin-based composites, alumina (Al_2O_3) nanoparticle composites, $Ca_3(PO_4)_2$ and calcium fluoride (CaF_2) nanoparticle-based nanocomposites, and ormosers (organically modified ceramics) with fillers in the range of 1-100 nm (47–49).

1.1.5.3. Use in dental adhesives

It is common to use polymerizable silane-treated filler particles to increase the strength of dental adhesives that provide material interdental adhesion-cohesion. Because adhesives are not very viscous, filler particles have a tendency to settle during storage. To overcome this disadvantage, SiO_2 and ZrO_2 nanoparticles of 5-7 nm are added to the adhesives. These particles are so small that they cannot be seen with the naked eye and are not affected by gravity, and stable suspensions can be obtained without a reduction in bond strength (50). With the addition of nanoadhesives, bond strength to enamel and dentin can be increased, and a longer shelf life can be achieved. By adding nanoparticles such as ZrO_2, radiopacity can be gained (47).

1.1.5.4. Use in composite dentures

In removable dentures, teeth made of materials such as porcelain and acrylic are used, but acrylic teeth wear over time. Nanocomposite dentures contain homogeneously dispersed nanofillers and polymethyl methacrylate. They show high durability and polishability, increased shear strength, superior aesthetics and higher wear resistance (51).

Abbas and Sakr (52) compared the wear rate between nanocomposite and acrylic dental materials containing 75 nm SiO_2 nanoparticles and showed that nano-composite dentures have higher but similar wear resistance than PMMA dentures.

1.1.5.5. Use in tissue conditioners

Tissue conditioners are widely used to heal tissues in removable prostheses. These materials degenerate over time and become susceptible to colonization by microorganisms. The addition of Ag nanoparticles to tissue conditioners provides antimicrobial properties against S.aureus, S.mutans, and C.albicans (48,49). Nam (53), after an incubation period of 24 hours and 72 hours in tissue conditioners supplemented with Ag nanoparticles, S.aureus, S.mutans, and C.albicans showed that it exhibited antimicrobial properties against albicans.

1.1.5.6. Use in soft lining material

Soft prosthetic lining material is used to reduce the forces transmitted to the supporting tissues and to prevent trauma. Soft linings can cause differentiation of material structure due to high humidity and high temperature under the dentures. This causes an increase in pathological microorganisms. It has been shown that the addition of TiO_2, chlorhexidine, or Ag nanoparticles in high concentrations into the soft lining material has antimicrobial activity against candida species and is effective in preventing denture stomatitis (42,54). Garner et al. (55) showed that the addition of CHX nanoparticles to dental silicones prevented denture stomatitis by providing an antifungal effect against C.albicans, which plays a role in oral fungal infections in removable dentures.

1.1.5.7. Use in dental cements

By adding nanoparticles to dental bonding cements, properties of cements such as fracture toughness, bending strength, compressive strength and antibacterial activity have been improved. It is very important for dental cements to show antibacterial properties, and Ag nanoparticles have been added to dental cements for this purpose. Resin composite cement containing Ag nanoparticles has been shown to have a long-term antibacterial effect against S.mutans and has good mechanical properties (48).

It has been found that nanoparticle-added dental cements provide a significant increase in bond strength compared to conventional cements and have very good bonding to dentin tubules and reduce polymerization shrinkage (56). In Karimi et al. (57)'s study, ZnO and MgO nanoparticles were added to improve the compressive and tensile strength of zinc polycarboxylate cement, and they showed excellent physical and mechanical strength compared to conventional zinc polycarboxylate cements.

The addition of nano-HA/fluorapatite and TiO2 particles to glass ionomer cements significantly increased compressive, tensile, and biaxial flexural strengths compared to conventional glass ionomer cements (58,59).

1.1.5.8. Use in impression materials

An ideal impression material should be biocompatible, have a suitable density but a fluidity to give details, be hydrophilic, provide dimensional stability, and have elasticity. In order to provide these properties and to improve the physical and mechanical properties of the impression materials, nanoparticles can be added.

The addition of nanoparticles to polyvinylsiloxanes, which are impression materials, improves their hydrophilic properties, fluidity, and clarity compared to conventional polyvinylsiloxanes (60). It exhibits high tear resistance, resistance to degradation and increased fluidity. The slip-cast feature and heat resistance reduce the errors caused by movements during impression (20).

The antimicrobial properties of impression materials such as alginate can prevent cross-infections. Nano-Ag particles can be added to impression materials due to their antibacterial properties (61). Omidkhoda et al. (61) showed that the addition of Ag nanoparticles at 500 ppm and 1000 ppm concentrations to the alginate material reduced the growth of E.coli, S.aureus, and C.albicans on the alginate surface, but did not completely prevent it.

1.1.5.9. Use in maxillofacial prosthesis

Maxillofacial prostheses are made of various artificial materials such as silicone, polyvinyl chloride, polymethyl methacrylate, polyurethanes, and chlorinated polyethylene. In addition to the positive features such as acceptable tear, tensile, high mechanical strength, and ease of production, silicones have negative features such as discoloration, deterioration of their physical and mechanical properties, and repair difficulties. In addition, it has disadvantages such as short usage time and contamination. In order to overcome these problems, better strength and flexibility can be achieved by adding many nanoparticles to it.

Due to its antibacterial properties, Ag nanoparticles were added to the materials and it was observed that it prevented C. albicans from adhering to the surface of these prostheses (62).

Silicone elastomers are very sensitive to tearing due to the mobility of facial structures such as the eyes, mouth, and nose. The addition of nano-sized Ti, Zn or Ce oxides in concentrations of 2.0-2.5% by weight increases the tear and tensile strength and stretching percentage to have certain flexibility for ideal facial prostheses (63,64).

Polymer molecules are more sensitive to ultraviolet (UV) light, and when exposed, it degrades and causes the molecules to break into smaller pieces and changes the shape of the molecule. Nano-sized ZnO, TiO2 and cerium dioxide (CeO2) are mainly used as UV shields (63).

Pigments are added to the silicone elastomer material to color the maxillofacial prosthesis material (65). Han Y. et al. (66) studied the color stability of pigmented maxillofacial silicone elastomer, nano – TiO2, ZnO, and CeO2 were used as opacifiers for the silicone elastomer, and TiO2 and CeO2 caused the least color change.

1.1.5.10. Use in dental ceramics

In prosthetic dentistry, ceramics have become increasingly common in restorative materials due to their aesthetic properties, chemical stability, biocompatibility, low plaque accumulation, low thermal conductivity, and radioactivity compared to metal alloys (67,68).

Dental ceramics are obtained by mixing kaolin, quartz, and feldspar at high temperatures (69). Apart from these three main substances, various color pigments, intermediate oxides, glass modifiers, opacity, and gloss additives can be added to their structures (70).

During the last 20 years, studies have focused on the strengthening of dental ceramics by modifying their microstructure, and different ceramic materials have been produced by adding particles of different sizes to the material content. Particles of nano-size have been used to develop ceramics in recent years.

The composition, microstructure and properties of ceramics determine various ceramic classifications and clinical indications. Ceramics vary in production techniques, infrastructure, microstructure, etc. classified in many different ways. Gracis et al. (71) according to their structural characteristics, dental ceramics and ceramic-like materials are divided into three main groups as glass matrix ceramics, resin matrix ceramics, and polycrystalline ceramics.

– Glass Matrix Ceramics; It contains glass phase, nonmetallic, and inorganic ceramic materials. It is divided into subgroups as feldspathic, synthetic, and glass infiltrated ceramics.
– Feldspathic ceramics is a traditional ceramic group consisting of feldspar, quartz, and kaolin. They are the most translucent and aesthetic materials and have disadvantages such as low flexural strengths, and brittleness.
– Synthetic ceramics are grouped under three headings: leucite-based, lithium disilicate-based, and fluoropatite-based (71).

Zirconia reinforced lithium silicate ceramics (ZLS); are obtained by adding approximately 10% by weight of zirconia to glass-ceramics. Crystal particles (0.6-0.8 µm) in ZLS ceramics are significantly smaller than crystal particles (2.5 µm) in conventional lithium disilicate glass ceramics, but larger than particle sizes in nanoceramics (72).

– Glass Infiltrated Ceramics; are possible to divide glass infiltrated ceramics into 3 groups as alumina, alumina and magnesium, and alumina and zirconia.
– Resin Matrix Ceramics; are mainly polymer matrix materials with durable inorganic content such as glasses, porcelains, ceramics and glass ceramics. Resin nanoceramics are divided into subgroups as glass-ceramics in the resin matrix and zirconia-silica ceramics in the resin matrix.
– Resin Nanoceramics are ceramic materials containing nanoparticles to improve the deficiencies of dental ceramics. Atoms added to a nanoscale structure can cause different changes in physical properties. While the material is mechanically weakened or strengthened, another property may change completely and different physical properties may emerge. Nanoceramics have been shown to be more durable and have higher wear resistance than restorations made from conventional ceramics, acrylic materials, and microfilled composites. Many nanoceramics have higher hardness and strength than conventional materials (49,73,74).

One of the materials in this group is a material consisting of 80% of its weight in a resin matrix by adding nanoceramic particles. The nanoceramic, that is, the inorganic part, forms SiO_2 nanoparticles with a diameter of 20 nm, ZrO_2 nanoparticles with a diameter of 4-11 nm, and SiO_2 – ZrO_2 nanoclusters that fill the gaps between the filler (71).

In another nanoceramic material produced by nanotechnology, 20 nm SiO_2 and 300 nm barium glass fillers constitute 71% of the inorganic part by weight. Having a dentin-like modulus of elasticity and high-stress absorption without deterioration, it is one of the most recommended materials to produce crowns on implants (69,75,76).

– Resin matrix glass-ceramics are ideal restorative materials formed by combining composites with elastic modulus close to dentin and feldspathic ceramics with elastic modulus close to the enamel. Its contents are 86% by weight of feldspathic ceramic enriched with aluminum oxide, while the organic matrix is composed of UDMA and TEGDMA monomers (76).
– Resin Matrix Zirconia-Silica Ceramics consists of 85% inorganic and 15% organic matrix consisting of different monomers. This material is the first resin composite material shaped by Computer Aided Design/Computer Aided Manufacturing(CAD/CAM), consisting of 85% by weight ZrO_2 – SiO_2 ceramic particles. ZrO_2 – SiO_2 filler particles are synthesized by the sol-gel synthesis method with a spherical shape and average particle size of 0.6 µm (77).
– Polycrystalline Ceramics are nonmetallic, inorganic ceramic materials and do not contain any glass phase. They are divided into the following subgroups; alumina, stabilized zirconia, zirconia reinforced alumina and alumina reinforced zirconia ceramics.
– Alumina ceramics contain high purity Al_2O_3 in amounts reaching 99.5%. It is produced with CAD/CAM system to be used as core material.
– Zirconia Reinforced Alumina and Alumina Reinforced Zirconia Ceramics contain alumina and zirconia in micro or nano scales. Zirconia-reinforced alumina (ZTA, zirconia-toughened alumina) and alumina-reinforced zirconia (ATZ, alumina-toughened zirconia) ceramics have been developed because zirconia is generally partially stabilized in the tetragonal phase, and alumina has a durable structure. It is recommended that ZTA contains at least 50% alumina, and ATZ contains at least 50% zirconia (71).
– Stabilized Zirconia Ceramic is one of the most preferred ceramic metals in recent years due to its high mechanical strength. It can be found in nature in the forms of ZrO_2 and zirconium silicate ($ZrSiO_4$). Pure zirconia exists in three crystalline phases. It exists in the monoclinic (m) phase at room temperature, in the tetragonal phase (t) above ~1170°C, and in the cubic (c) phase above ~2370°C (78). When unstabilized zirconia is heated above the phase transition temperature and cooled at room temperature, its crystal structure changes from the tetragonal phase to the monoclinic phase. Zirconia does not have sufficient mechanical strength in the monoclinic phase, so stabilizing oxides such as Calcium Oxide (CaO), Magnesium Oxide (MgO) and Yttrium Oxide (Y_2O_3) are added to its composition in order to keep it partially stabilized in the tetragonal phase at room temperature (79,80).

First-generation Zirconia Polycrystals (3Y-TZP) stabilized with 3 mol% yttria show very good mechanical strength. Phase transformation from tetragonal to monoclinic in the material provides high mechanical strength due to volume increase in crystals (79–81).

First-generation zirconia has high opacity due to its 0.25% aluminum oxide content by weight (78,82). This material can be used both as a substructure and as a two-layer (83,84). For the monolithic use of zirconia, the number of Al_2O_3 grains has been reduced, the particle size has been reduced, the sintering temperature has been increased compared to the first generation, and this material is called second-generation zirconia, but the strength and light transmittance were not found sufficient (78,85).

Third-generation yttria partially stabilized or fully stabilized zirconia polycrystals (Y-PSZ, Y-FSZ) produced to obtain more aesthetic and translucent monolithic restorations have been introduced. Due to the higher Y_2O_3 stabilizer content (approximately 5-9.3 moles by weight) compared to the first and second generation, it is not only metastable in the tetragonal phase but also contains a cubic phase ratio of up to 53% (85,86). However, while the increase in the cubic phase is an advantage as it increases the translucency, it is a disadvantage that it causes a decrease in the tetragonal-monoclinic phase transformation ratio formed by stress in zirconia. Because by reducing the hardness of the material, it causes a decrease in strength and a decrease in its mechanical properties (78,86,87).

In a few studies conducted in recent years, it has been tried to increase the strength of the material by eliminating the negative effects of the mechanical surface treatments applied to the crowns with nanoparticle coating methods on monolithic crowns. For production and harmonization with CAD/CAM systems, etching, finishing, and polishing operations are required (88,89).

The applied surface treatments can cause topographic changes, damage, and t-m phase transformation in dental zirconia (84). In the case of cracks in the material due to mechanical, physical, and chemical stimuli, the phase of the crystals around the crack changes from tetragonal to monoclinic and causes a 3-4% volume increase in the crystals. This increase in volume can provide high mechanical strength to the material by forming a compressive stress layer that absorbs energy and stops crack formation and propagation. However, the increase in stimuli can also create a negative effect by causing excessive cracks and a decrease in the strength of the material (79–81). Compared to the first and second generations, the third generation zirconias, which contain up to 53% cubic phase ratio, have lower hardness and strength than the previous generations due to the reduction of the tetragonal-monoclinic phase transformation ratio that occurs with stress in the zirconia (86).

1.1.5.11. Use in dental glaze material

Dental glaze application is applied to provide aesthetics in ceramic restorations and to smooth rough surfaces (90). In various articles, the changes in the physical and mechanical properties of ceramics by adding various nanoparticles into the glaze material were investigated.

Venkatesh et al. (91) added the nano-ZrO_2 particles synthesized using the sol-gel method into the glaze at different rates and showed that the increase in the nano-ZrO_2 content directly increased the wear resistance of the material. Moosa et al. (92) applied a glaze containing nano-Al_2O_3 with 13nm particle size at different rates on zirconia restorations and determined that it was effective in increasing the resistance of the restoration.

In order to increase the strength and mechanical properties of zirconia material, the idea of coating the material with nanoparticles has been studied by several researchers.

Okada et al. (93) researched on the durability of Y-TZP material coated with 21 nm monoclinic phase ZrO_2 nanoparticles obtained by hydrothermal method. They stated that due to the smaller thermal expansion coefficient of the mZrO_2 coating layer compared to the Y-TZP material, compression stresses occur after thermal heat treatment, and this increases the mechanical strength of zirconia.

Uno et al. (79) applied a solution containing SiO_2 and m ZrO_2 nanoparticles obtained by hydrothermal method to translucent Y-PSZ material at different rates and temperatures; its mechanical properties were investigated, and they showed that the flexural strength of the coated samples at 10/1 mZrO_2/SiO_2 ratio and heat treatment at 1500°C increased significantly compared to other samples and sintered Y-PSZ. It was determined that the flexural strength increased significantly compared to the control group.

In Fujii et al. (94)'s study to increase the mechanical strength of the highly translucent Y-PSZ material with a yttria content of 5 mol%, 20-50 nm nano-ZrO_2 particles in monoclinic phase were used as coating material. Heat-treated samples showed a significant increase in mechanical strength compared to the control group.

2. CONCLUSION

In the fields of dentistry and prosthetic dentistry, nanotechnology is frequently used in the production of new materials that will increase the potential applications and benefits compared to the traditional materials used. This technology increases the quality of dental biomaterials and produces materials with much better properties. It offers useful features for better diagnosis, treatment plans, and the improvement and protection of oral health. Due to their superior physical, mechanical, chemical, and biological properties, nanomaterials have recently gained importance in many dentistry fields, especially prosthetic treatments. However, in vitro studies on the use of different nanoparticles in dental materials, their safety, effectiveness, and applicability are not sufficient. More studies and data are needed on the use of nanoparticles in the dental field.

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