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Review Derleme

NANOPARTICLES IN PROSTHETIC DENTISTRY

PROTETİK DİŞ HEKİMLİĞİNDE NANOPARTİKÜLLER

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ABSTRACT

Objective: The aim of nanotechnology, which is within the scope of new developments in the field of health, is to develop and produce materials at molecular/atomic level and to offer biomaterials with better properties. In this context, nanoparticles such as titanium dioxide, silver, zirconium, gold, etc. may be used for purposes such as providing antimicrobial properties and mechanical advantages in dentistry applications.

Conclusion: The purpose of this review is to give general information about the use of nanoparticles in prosthetic dentistry.

Key Words: Nanotechnology, Nanoparticles, Prosthodontics.

ÖZ

Giriş: Sağlık alanındaki yeni gelişmeler kapsamında yer alan nanoteknolojinin amacı, atomik ve moleküler düzeyde materyaller geliştirip üretmek ve daha iyi özelliklere sahip biyomalzemeler sunmaktır. Bu kapsamda titanyum dioksit, gümüş, altın, zirkonyum vb. metal nanopartiküller diş hekimliği uygulamalarında antimikrobiyal özellikler ve mekanik avantajlar sağlama gibi amaçlarla kullanılabilirler.

Sonuç: Bu derlemenin amacı nanopartiküllerin protetik diş hekimliğinde kullanımı hakkında genel bilgi vermektir.

Anahtar Kelimeler: Nanoteknoloji, Nanopartikül, Protez.

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GİRİŞ

Nanotechnology, which has become one of the active research areas in health sciences in recent years, provides nanoscale production of structures and also functional materials by using various physical and chemical synthesis methods (1, 2). Nano science is defined by the US department of National Nanotechnology Initiative as "fundamentally new advanced technology of small structural elements at ultra-small levels that enables almost complete control of the structure of matter at nanoscale dimensions". The particles used and known as "nanoparticles" are usually defined as a particle of matter that is between 1 and 100 nanometres (nm) in diameter (3). In order to synthesize nanomaterials such as nanocomposites, nanoceramics, nanoscale surface modifications etc. multidisciplinary approaches are needed. Also numerous nanofabrication technologies involving lithographie such as photolithographie, electon beam. and chemical vapor deposition, thin film deposition can be used (4). In this context, the use of nanoparticles to improve the chemical, physical and mechanical features of many dental products in dentistry has become very popular in recent years (2).

Nanodentistry Approaches

Nanomanufacturing involves the cost-effective invention of nanoscale materials, structures, and advanced devices. Including the field of dentistry, there are two main approaches in nanomanufacturing, either top-down or bottom-up. Top-down manufacturing reduces large pieces of materials down to the nanoscale, whereas the bottom-up approach creates products by building them from atomic and molecular scale components (5). In this context, as new technology bottom-down approaches has been applied by producing tooth sealant in restorative dentistry as nanocomposites, nanostructured dental implants in dental implantology, nanoparticles based impression materials. For inducing anesthesia, antibacterial drug, bone and tissue engineering and nanorobotic dentifrice, bottom-up approach is used in nanodentistry (6).

Nanoparticles In Prosthodontics

Nanotechnology research on dental materials has mainly focused on two areas; the preparation of new inorganic nanoparticles and the modification of surface with inorganic nanofillers. Nanomaterials are especially used in ceramics, resins, and metals, which have crucial field in prosthetic dentistry applications (7). In order to reduce porosities and thus the bacterial attachment on denture base material, the impregnation of some nanoparticles such as titanium dioxide or irone oxide has shown to be superior. Also titanium dioxide and silver nanoparticles inserted on denture resins have reduced the adherence of candida species. To improve the mechanical properties carbon nanotubes are used to reduce the polymerisation shrinkage. Meanwhile, zirconium dioxide nanoparticles are used to increase flexural strength and alumina nanoparticles for hardness. For their good bactericidal properties cobalt and cobalt oxide nanoparticles have been recommended. Nanofillers like nanoparticles of zirconia, alumina, carbon nanotubes and titanium have been trialled in composite resins. For their antimicrobial properties zinc oxide, copper oxide, silver and chlorhexidine nanoparticles have been used in dental implants (8).

1. Acrylic Resin

Acrylic resins are organic compounds that are frequently used in the fabrication of denture bases, orthodontic appliances, temporary prosthetics and restorations based on polymethyl methacrylate - a polymer in powder form and a methyl methacrylate - a monomer in liquid form. As a result of polymerization reaction biocompatible, low cost and color stability dentures are produced. Despite the advantages, poor mechanical properties and biological activities of polymethyl methacrylate materials lead to extensive range of methods to be developed for better features (9).

Antimicrobial activities of titanium dioxide against gram-positive and gram-negative bacteria, fungi, and viruses etc. stated by recent studies (10). Titanium dioxide nanoparticles have been proven to impart antimicrobial properties to biomaterials when used as additives for inducing function. Sodagar et al., (2016) investigated the antimicrobial activity against Lactobacillus acidophilus and Streptococcus mutans under different light conditions by adding titanium dioxide, silicon dioxide nanoparticles and their combinations to polymethyl methacrylate (PMMA). The study results showed that antimicrobial activity of titanium dioxide was significantly higher than the activity of silikon dioxide under ultraviolet. A illumination and visible light. 1% nano-TiO_2 reduced Lactobacillus acidophilus and Streptococcus mutans viability by 93%. Under ultraviolet A illumination antibacterial effect on these bacterial cultures was 92% (11).

Harini et al., reported that by the addition of titanium dioxide nanoparticles at different concentrations (1%, 2%, and 5%), flexural strength values of acrylic resins were increased (12). Contrary to this result, Ahmed et al., (2016) stated the decrease in flexural strength values of traditional heat polymerized and high resistance heat-polymerized acrylic resin by increasing titanium dioxide nanoparticle concentration to 5%. On the other hand, in the current study microhardness was significantly increased by addition of 5% of titanium dioxide (13). Silver nanoparticles have been used as antimicrobial agent since they are small in sizes and therefore have greater distribution within the polymethylmethacrylate (PMMA) matrix film and produces oxide layer. Moreover, the antibacterial mechanism of silver nanoparticles is by releasing silver ions than disrupting the peptidoglycan cell wall blocking cell respiration, causing protein denaturation and eventually causing cell death (14). Acosta-Torres et al., incorporated 1g/mL of silver nanopatrticles to poly (methyl methacrylate) and compared this new compound with unmodified PMMA. Silver nanopatrticles in PMMA specimens showed successful reduction of adherence of candida albicans, demonstrating the antifungical potential of silver nanoparticles incorporated to acrylic resin. The developed PMMA-silver nanoparticle compound also was not found to be cytotoxic or genotoxic (10).

Among the compounds such as zeolite nanoparticles are very porous in their structures and have adsorption characteristics, therefore the most promising zeolite compound is silica dioxide. Silica dioxide nanoparticles indicates extremely high surface activity and adsorb various ions and molecules (15). A recent in vivo study tested the biocompatibility of silicon dioxide nanofilms as antimicrobial agents on acrylic surfaces and demonstrated that coating with nanofilm NP-Liquid Glass had the best cell repair capability and showed the highest level of tissue compatibility, thus being highly promising for use in clinical practice (16). But previous studies showed that silica incorporation into acrylic resin decreased flexural strength when compared with the unmodified or titanium and aluminum nanoparticle added PMMA (17). Zinc oxide (ZnO) nanoparticles have also been receiving attention recently. Zinc oxide nanoparticles are used to increase the hardness, thermal stability and can present antifungal properties as well, when incorporated to PMMA (18). Cierech et al., researched to obtain a composite denture material with antifungal properties that can be used as an alternative protocol in denture stomatitis treatment. Test was conducted with varie concentrations of zinc oxide nanoparticles (2.5%, 5%, 7.5%) and PMMA. The study demonstrated the increasing antifungal activity of nanocomposite PMMA depended on increasing nanoparticle concentration (19).

Graphen is also a material with unique mechanical properties and is therefore applied in nanocomposites of different polymeric structures. Lin et al., stated that in a low modulus polymeric matrix the presence of high elastic modulus graphen creates an important reinforcement (20). In another study Bacali et al. investigated the mechanical properties of graphene-silver nanoparticles added PMMA and detected homogeneus stress distribution and an increase in mechanical strength (21). Incorporation of zirconium dioxide and also gold nanoparticles into PMMA improves antimicrobial effect and mechanical properties (22). Tijana et al. formulated PMMA gold nanoparticle composite in different concentrations and investigated flexural strength, elastic modulus, thermal conductivity, density and hardness properties of the material. Incorporation of gold nanoparticles into heat-polymerised PMMA resin resulted a decrease in flexural strength and elastic modulus. However, the density, thermal conductivity and hardness properties improved gradually by increasing volume fraction of the gold nanoparticle (23).

Regarding acrylic resin materials apart from the mentioned nanoparticles, studies have also been carried out with different nanoparticles. In this context, there are studies expressing that the flexural strength and surface roughness are improved by adding low concentrations of nanodiamonds to the acrylic denture base (24).

2. Tissue Conditioners

Tissue conditioners which are widely used to enhance the recovery of denture bearing tissues from trauma, damage or residual ridge resorption usually caused by ill-fitting dentures degenerate over time and become prone to colonization by microorganisms (25). To overcome this challenge tissue conditioners has been modified with silver nanoparticles. Effective antimicrobial properties results mostly due to concentrations of silver nanoparticles. An experimental in vitro study by Nam aimed to identify the antimicrobial activities on varios microorganisms. He suggested that adding 0.1 % to 0.3 % of silver nanoparticles into a tissue conditioner and evaluated against several microorganisms. The author reported that Ag nanoparticles could be used as antimicrobial dental material in denture plaque control (26). In another study that performed by Mousavi et al. incorporation of ZnO–Ag nanoparticles into tissue conditioner samples resulted in a decrease in the growth of Streptococcus mutans. Incorporation of 0.625 wt% of nanoparticles resulted in a significant decrease in the growth of Streptococcus mutans compared to the control samples (27).

3. Dental Adhesives

Dental adhesives are resin monomers that deals with adhesion between dissimilar materials like hard tooth enamel and dentin. To increase the cohesive strenght, polimerizable silane is added to dental adhesives. Because the adhesive liquid is not very viscous the filler particles tend to settle during storage, resulting in inconsistent form. To overcome this limitation, aggregates of silica or zirconia can be added to dental adhesives (28). To improve the mechanical properties and resistance to degradation, a small amount of fillers such as titanium dioxide nanofillers (TiO2) can be added into dental adhesives. Sun et al. combined titanium nanoparticles with acrylic acid and produced agglomerated fillers. Those agglomerated fillers were added to a mixture of bis-phenol-A-dimethacrylate and triethylene glycol dimethacrylate (mass ratio 1:1) at seven mass fractions. The degree of conversion was improved and was higher, approximately 5% more than the control group. The flexure modulus was increased by about 48% and the hardness was almost double. These findings could lead to better performing dental adhesives (29). In another study Welch et al. investigated the performance of a novel dental adhesives incorporating TiO2 nanoparticles to obtain combined properties of bioactivity and bactericidal effect and the antibacterial effect of TiO2 nanoparticles has been proven (30). In another study, Yasumoto et al. used colloidal platinum nanoparticles as a pre-treatment on dentin after acid etching and before adhesive application to improve resin polymerization and reported enhanced bond strength (31).

4. Composite Resin

The development of nanocomposites with the discovery of nanoparticles has been useful for solving the problems of polymerization shrinkage, durability, microhardness and wear resistance. In this context, nanofiller and nanohybrid are commonly available types of nanocomposites. Nanofillers consist of particles from 1 to 100 nm, while nanohybrid resins consist of larger particles ranging from 0.4 to 5 μm (32). The advantage of nanofillers in dental composites are; not thickening the resin, increasing the polishing property, providing hardness and wear resistance, reducing polymerization shrinkage, providing superior flexural strength and modulus of elasticity with an aesthetic appearance (33). To improve the handling propertis of composites and esthetic properties, larger particules or prepolymerized organic fillers are added and these materials are called nanohybrid composites. Nanohybrid composites have a smoother surface and lower susceptibility to color change compared to nanofillers composites (34). But studies have proved that contrary, after polishing nanofilled compostite surface roughness is better than nanohybrid composite. In a comparation study between nanofillers and nanohybrid composites that conducted by Itanto et al. after polishing with multi-step technique, it was shown that nanofilled composite surface roughness after was better than that of nanohybrid composite. Nanofilled composite surface had homogenous and filler particles spreading evenly, conversely nanohybrid speciemens shown irregular filler appereance (35). Zhang et al. expressed in a study measuring suface roughness and gloss values of nanofilled, nanohybrid and microhybrid composites before and after polishing that, microhybrid composites presented lower gloss value and irregularites (36).

5. Dental Porcelain

Nanostructured ceramics may meet the translucency and mechanical improvement requirement of dental restorations (37). Fujieda et al. that the addition of noble metals in dental porcelain improves the mechanical properties of porcelain. According to the study, the addition of silver and platinum nanoparticles increased both Young's modulus and fracture toughness of dental porcelain whereas silver nanoparticles increased the fracture toughness more than platinum (38). Uno et al. showed that incorporation of silver nanoparticles into dental porcelain significantly increased the materials fracture toughness. At the same time Vickers hardness also increased but the silver nanoparticles led to a porcelain color changes (39). Li et al. reported in their study that nano-ZrO2 ceramic materials have different physical properties from conventional ones. The hardness of traditional ZrO2 is usually around 1500 Hv (hardness), and because the fracture toughness is very low, it can easily break or crack during processing. However, the hardness of nanozirconia ceramics is approximately 20% higher, and fracture toughness is better (40)

To prevent the accumulation of microorganisms and formation of biofilm on dental materials is of great importance. Beside antimicrobial substances used in dental field new nanomaterials come as an alternative to prevent biofilm formation. In a recent study, Vidal et al. incorporated nanostructured silver vanadate decorated with silver nanoparticles (β-AgVO3) into dental porcelains at different concentrations (2.5 % and 5 %). This nanomaterial dissociates into silver (Ag+) and vanadium (V4+ and V5+) ions and acts on bacterial structures. This study evaluated antimicrobial activity, surface characteristics and fracture toughness, roughness and microhardness of two different dental porcelain. The results showed that β-$AgVO_3$ promoted antimicrobial activity against tested microorganisms, it improved fracture toughness and did not effect the microhardness of dental porcelains. However, the incorporation of β-$AgVO_3$ increased the dental porcelains surface roughness. The dental porcelains impregnated with β-$AgVO_3$ caused release of a higher percentage of vanadium than silver ions (41).

6. Impression Material

The addition of inorganic and organic fillers to impression materials increases the mechanical properties and durability of polymer structure (42). In most applications, silica is the main reinforcing filler that used to improve the properties of vinyl polysiloxanes, while non-black fillers such as calcium carbonate, diatomite and glass fiber can also be used (43). Shao-Yun et al. stated that the fillers have sizes ranging from 10 nm-80 nm to 1.3 µm- 58 µm, and that the tensile strength of the material increases as the filler size decreases for a given filler volume (44). This indicates that the resistance increases with the increase in filler surface area and smaller filler sizes better able to replicate small areas. Materials with a smaller amount of filler have a lower viscosity and as a result show a greater probability of distortion (42).
In a study Sheta et al. compared impression materials of polyvinyl siloxane containing nanofillers, vinyl polyether silicone hybrid material, conventional polyvinyl siloxane and polyether impression materials. They evaluted and compared wettability by measuring contact angles, comparing dimensional changes, flexibility by comparison of strain in compression and tear resistance of different material types. Polyvinyl siloxane incorporated with nanofillers has shown significant dimensional stability and lowest strain in compression. Higher strain in compression values indicates more flexibility and experimented materials showed accepted flexibility. The impression materials mechanical properties rely on there consistencies. A flexible impression materials are expected to have more plasticizer, less fillers and by adding low-viscosity softeners researchers expect to reduce the stiffness of the polymerized materials. Meanwile, polyvinyl siloxane containing nanofillers and vinyl polyether silicone hybrid material showed the highest tear resistance (45).

7. Implants

Titanium materials are the best option for dental implants nowadays due to their biocompatibility, but they still need to be improved (46). Hydroxyapatite coatings for implant are the main components that has became widely used during the last decade. Various types of nanostructured hydroxyapatites are capable of promoting osteoclast activity and osteoblast proliferation, also bone development and mineralization, most importantly plays role in bone formation around implant. To improve implant properties, nanoporous ceramic implant coatings are performed by forming a nanoporous aluminum layer on implants, using a different approach, such as anodization of aluminum. Nanoporous alumina has the potential to improve cell response and facilitate osseoinductive activity (47).
Graphene oxide consists of chemical oxidation of graphite and is few-layered or monolayers exfoliated stacks of graphite oxide, with each layer 1 nm thick and 400-500 mm long. Graphene oxide is compound with great mechanical properties and can improve implant surface properties and prevent corrosion (46). Suo et al. prepared a graphene oxide (GO), chitosan (CS), hydroxyapatite (HA) composite coating produced by electrophoretic deposition on the Ti material. The aim of the mentioned article was to develope a osseointegration between implant and bone, and to increase the properties of hydroxyapatite coatings. The addition of chitosan improved the coating adhesion on the Ti surface of the hydroxyapatite coating and facilitated osseointegration. In the study, it was obtained that GO/CS/HA - Ti composite coating has created dense and uniform surface and this lead to better wettability and hydrophilicity. Additionally, GO and CS added into the HA coating on Ti, singnificantly improved osseointegration (48).

8. Maxillofacial Prosthetics

Maxillofacial prostheses, which are used to modify body parts in particular facial parts which have been lost due to disease or trauma, routinely are made from artificial substitutes such as silicone. Materials in use are exposed to a bacterial colonization due to saliva and nasal secretion, also contamination and infection of surrounding tissues are common risks for patients. It gives variable clinical results in terms of stability. In studies where silver nanoparticles were included in maxillofacial prostheses, it was observed that the coating was effective on silicone surface. Fungal growth was prevented without damaging fibroblast cells (49, 50). In studies on the subject, titanium dioxide, zinc oxide and cerium dioxide nanoparticles were added to silicon elastomers as opacifiers, and it was observed that titanium dioxide and cerium dioxide nanoparticles exhibited the least color instability and also surface treated silicone dioxide nano particles increased the mechanical properties and especially the tear strength (51). Also the use of polyhedral oligomeric silsesquioxane against tensile and tearing loads, which are the main causes of mechanical problems in maxillofacial prostheses, increased the tensile and tear strengths of conventional materials (52).

CONCLUSION

The use of nanoparticles in dental and specifically in prosthetic applications may improve treatment results. Further studies are needed to evalute and to develop the mechanical and biological properties of nanoparticle added dental materials in terms of biocompatibility, mechanical stability and cytotoxicity.

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