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Some aspects of using modern innovative nanotechnologies in dentistry technical solutions, dilemma of implantation

Algunos aspectos de la utilización de nanotecnologías innovadoras modernas en odontología soluciones técnicas, dilema de la implantación

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Abstract

In the article, the authors analyze the problem of using modern innovative nanotechnologies in dentistry. Currently, nanotechnology is used in treatment, prosthetics, preventive care of the oral cavity and teeth. Based on this, the use of nanotechnology in dentistry has a number of advantages compared to the traditional materials used, as they are more effective, affordable, structured, meet all modern parameters, and have high quality. Despite the widespread use of nanotechnology, in some cases, they may carry certain risks. Nanomaterials have higher activity, high permeability through the skin, lungs, and digestive tract. But the impact of nanoparticles on the body remains unexplored. In addition to safety problems of nanomaterials, their production is associated with a number of other problems: engineering, biological, and social. Specialists think about new ways to solve current

Resumen

En el artículo, los autores analizan el problema del uso de nanotecnologías innovadoras modernas en odontología. Actualmente, la nanotecnología se utiliza en tratamientos, prótesis y cuidados preventivos de la cavidad bucal y los dientes. Según esto, el uso de la nanotecnología en odontología tiene una serie de ventajas en comparación con los materiales tradicionales utilizados, ya que son más eficaces, asequibles, estructurados, cumplen todos los parámetros modernos y tienen una alta calidad. A pesar del uso generalizado de la nanotecnología, en algunos casos pueden conllevar ciertos riesgos. Los nanomateriales tienen mayor actividad, alta permeabilidad a través de la piel, los pulmones y el tracto digestivo. Pero el impacto de las nanopartículas en el organismo sigue sin explorarse. Además de los problemas de seguridad de los nanomateriales, su producción está asociada

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professional problems. Time will tell how successful the process of integrating narrow-profile research into practical activity will be. The development of new and implementation of existing nanotechnology medical technologies is a promising direction of the development of modern dentistry.

Keywords: nanotechnology, nanomaterials, nanoparticles, dentistry, medicine.

a otra serie de problemas: de ingeniería, biológicos y sociales. Los especialistas piensan en nuevas formas de resolver los problemas profesionales actuales. El tiempo dirá hasta qué punto tendrá éxito el proceso de integración de la investigación de perfil estrecho en la actividad práctica. El desarrollo de nuevas tecnologías médicas nanotecnológicas y la aplicación de las ya existentes es una dirección prometedora del desarrollo de la odontología moderna.

Palabras clave: nanotecnología, nanomateriales, nanopartículas, odontología, medicina.

Introduction

A beautiful smile not only boosts self-confidence, but also reflects the health of the body. The oral cavity contains many more different types of bacteria than other parts of the gastrointestinal tract, and this number ranges from 160 to 300 species. Inflammatory diseases of the oral cavity occur when the normal balance between the own and foreign microflora is disturbed. The originality and peculiarity of the oral cavity lies in the fact that, firstly, two vital functions of the human body are carried out through it and with its help - respiration and nutrition, and, secondly, that it is constantly in contact with the external environment. The mechanisms functioning in the oral cavity are under constant double influence - the influence of the body, on the one hand, and the external environment, on the other.

Oral hygiene is very important because it can have a significant impact on a person's health and quality of life (Lamster, 2021). Oral health received a lot of attention at the 74th World Health Assembly in 2021 (Lamster, 2021). The main common oral diseases are caries, periodontal disease, and tooth loss. Therefore, disease prevention requires special attention and innovation.

Conventional therapeutic approaches yield superficial outcomes that fail to achieve the desired effects. The emerging field of nanotechnology, particularly within the realms of dentistry and medicine, has sparked considerable interest among researchers due to its potential applications and the distinct advantages it offers compared to traditional materials.

The integration of nanotechnology into contemporary dentistry has facilitated the implementation of cutting-edge principles for addressing oral health concerns, specifically those pertaining to gums and teeth. The widespread adoption of nanotechnology within the dental field can be attributed to the robust growth of the oral hygiene industry, a progression that relies heavily on the introduction of inventive methodologies for acquiring products and sourcing raw materials. Nanotechnology finds application across various domains within dentistry, including radiography, orthodontics, surgery, and therapeutic interventions. Owing to their minuscule dimensions, nanoparticles exhibit exceptional penetrative capabilities, enabling effective tissue infiltration, filling, and pathogen combat. Today, many studies are being carried out simultaneously, looking at different ways of using nanoparticles for various dental purposes. It is believed that the beginning of the active development of nanotechnology was a report by Nobel Prize-winning physicist Richard Feynman in 1959. In 1968, Alfred Cho and John Arthur developed the theoretical basis for surface nanotechnology. In 1974, Norio Taniguchi coined the word "nanotechnology". In 1986, nanotechnology became known to the general public. The American futurist Eric Drexler published a book in which he predicted that nanotechnology would soon begin to develop rapidly. In 2000, the US Administration announced the National Nanotechnology Initiative. In 2004, the US Administration supported the National Nanomedicine Initiative as part of the National Nanotechnology Initiative.

Research Problem

Modern innovative nanotechnologies offer great promises for dental treatment enhancement, diagnostics, and preventive measures. However, the implementation of these cutting-edge technologies in dentistry is challenging. This article explored the research problem concerning the dilemmas faced in introducing and integrating modern innovative nanotechnologies in dentistry and delved the importance of this issue.

What are the challenges of implementing modern and innovative nanotechnologies in dentistry?

How can these challenges be overcome to improve oral health?

Why is it important to address this problem?

The importance of addressing the dilemmas of implementing modern innovative nanotechnologies in dentistry cannot be overstated. The lacks in the field have significant consequences for patients, dental health professionals, and society in general.

What consequences does it have for patients, dental health professionals or society in general?

For patients, unresolved challenges may result in limited access to state-of-the-art dental treatments, diagnostics, and preventive measures, hindering the improvement of oral health and overall well-being.

Dental health professionals will face difficulties i
n adapting and evolving technologies as well as delivering the highest standard of care if these challenges persist.

Society may suffer from missed opportunities to advance oral healthcare, contribute to overall healthcare system efficiency, and benefit from the societal and economic advantages that improved dental health can provide.

In conclusion, the research problem regarding the implementation of modern innovative nanotechnologies in dentistry is a critical issue that must be addressed to unlock the full potential of these technologies and promote improved oral health for individuals and society as a whole.

Thus, addressing these challenges is paramount to harness the full potential of modern nanotechnologies in dentistry and subsequently improve oral health.

Research Focus

The focus of the study is innovative nanotechnologies in dentistry.

Research Aim

The purpose of the study is to analyze some aspects of the use of modern innovative nanotechnologies in dentistry, their technical solutions and implementation dilemmas.

Let us examine the most recent research findings and publications in the domain of cutting-edge nanotechnology within the field of dentistry (Table 1).

Theoretical Framework or Literature Review

Table 1.
Research on the use of nanotechnology in dentistry

Authors	The subject of the study
Abduazimova-Ozsujlu et al. 2021	use of innovative technologies in dentistry
Vasiliu et al., 2021	application of nanotechnology and smart nanomaterials
Amissah et al., 2021	nanotechnology in the prevention and treatment of dental caries
Ni et al., 2019	use of nanoparticles in periodontal treatment
Omanović-Mikličanin et al., 2020	nanocomposites and matrix materials
Song, Ge, 2019	application and basic mechanisms of antibacterial nanoparticles in dentistry
Sun et al., 2019	nanoparticles in antibacterial applications

Source: author's own development

The analysis of scientific publications presented in Table 1 above is aimed at studying the field of dentistry and the introduction of nanotechnology in this area. We note the growing interest in the use of innovative technologies and nanomaterials in dental practice. The main areas of this research include the treatment of caries with nanoparticles, the use of nanotechnology for the prevention and treatment of caries, and the use of nanoparticles in the treatment of periodontal diseases. Table 1 of the authors' scientific papers illustrates the diversity of thematic areas and opportunities for further research in this area. It is important to take these scientific achievements into account when developing new methods and technologies of dental practice in order to improve the health of patients.

The results obtained indicate the potential of nanotechnology and nanomaterials to improve the quality of dental treatment and prevention. Therefore, it is necessary to continue research in this area to develop new effective methods and tools in the field of dentistry.

Today, the issue of using innovative technologies in dentistry is being studied (Abduazimova-Ozsujlu et.al., 2021). The replacement of so-called "passive" dental materials that do not interact with the oral environment with "smart/intelligent" materials that have the ability to change their shape, color or size in response to external stimuli such as temperature, light, humidity has received much attention in recent years. A strong trend in dentistry is the use of nanotechnology and smart nanomaterials, such as nanoclay, nanofibers, nanocomposites, nanobubbles, nanocapsules, solid lipid nanoparticles, nanospheres, metal nanoparticles, nanotubes, and nanocrystals. Among nanomaterials, smart nanoparticles have several advantages over other materials, creating the possibility of using them in various dental applications, including preventive dentistry, endodontics, restoration, and periodontal disease (Vasiliu et al., 2021). The need for and improvement of caries treatment methods using nanotechnology is being emphasized. Tooth decay occurs due to prolonged acid production when sugar is metabolized by a bacterial biofilm, which leads to the loss of calcium and phosphate from the enamel, so it is effective to use nanoparticles in the treatment.

Streptococcus mutans, an acidogenic bacterial strain, presents a formidable clinical challenge owing to its intrinsic resistance to established conventional therapeutic modalities, such as cefazolin and ampicillin. Furthermore, topical agents, notably fluoride, frequently exhibit suboptimal efficacy due to their susceptibility to rapid salivary clearance. Nonetheless, the incorporation of nanoscale drug delivery systems has yielded notable improvements in therapeutic outcomes. These enhancements stem from the enhanced solubility of therapeutic agents, augmented penetration into the deeper layers of the biofilm matrix, extended residence within the buccal cavity milieu, and a concomitant mitigation of the emergence of drug-resistant phenotypes. These pioneering advancements hold substantial potential in the rejuvenation of therapeutic agents characterized by limited physicochemical attributes, and they merit consideration for future research endeavors within the purview of Streptococcus mutans management (Amissah et al., 2021).

The restoration of the lost periodontal structure in the treatment of periodontitis remains a challenging clinical task due to the limited regenerative potential of cementum, periodontal ligament, and alveolar bone under the conditions of periodontal disease. Achieving periodontal tissue regeneration necessitates the regulation of the inflammatory response and subsequent differentiation of periodontal cells due to the infectious nature of the disease. It is worth noting that 45 nm gold nanoparticles (AuNPs) have demonstrated a significant anti-inflammatory effect and the ability to enhance the inflammatory microenvironment in periodontal tissues by influencing the production of inflammatory and regenerative cytokines and by modulating the polarization of macrophages. Consequently, they have an impact on the differentiation of human periodontal ligament cells (hPDLCs). These 45 nm AuNPs not only directly influence hPDLCs but also play a role in regulating the initial inflammatory response in periodontal tissues by modulating macrophage phenotypes. This creates an environment characterized by controlled levels of inflammatory cytokines and the presence of reparative cytokines such as bone morphogenetic protein-2 (BMP-2). This, in turn, facilitates PDLC differentiation, promotes the regeneration of periodontal tissues, and contributes to the prevention of periodontitis progression (Ni et al., 2019; Xue et al., 2019). The fundamental concepts of nanocomposites are introduced, and we delve into the types of matrix materials that categorize nanocomposites into three groups: metal matrix nanocomposites, ceramic matrix nanocomposites, and polymer matrix nanocomposites. Modifying the filling factor of silver nanoparticles by just 5 percent results in substantial alterations to both the actual and imaginary components of the effective permittivity of the nanocomposite material. In the context of a graphene-based nanocomposite, a notable absorption peak is detected when the silver filling factor reaches 0.2. Conversely, for a nanocomposite relying on graphene oxide, an absorption peak becomes evident at a silver filling factor of 0.1. In both scenarios, the highest level of absorption is witnessed in the nanocomposite material containing nanoparticles with a 5 nm radius (Omanović-Mikličanin et al., 2020; Khademi et al., 2019; Zafar, 2020). The above review of the current scientific literature discusses in detail the possibilities of using nanomaterials and nanopreparations in dentistry, which is of interest to various dental professionals, as these materials demonstrate new useful properties. Modern theoretical knowledge is being successfully implemented in practical dentistry, and nanomaterials have now become standard components of everyday dental practice. Some scientists also review the development, use, and underlying mechanisms of antibacterial nanoparticles in dentistry, including restorative dentistry, endodontics, implantology, orthodontics, dentures, and periodontics (Song, & Ge, 2019). Multifunctional nanoparticles also have great potential in the field of antibacterial applications aimed at preventing and controlling the progression of periodontitis (Sun et al., 2019). To date, many authors have published review articles discussing the potential of nanotechnology in dentistry, including newly developed materials, but the literature lacks reviews that describe in detail the science behind nanotechnology and link it to the significance and application of nanotechnology in dentistry.

Methodology

This review attempts to summarize and present the current data on the work of scientists and specialists in the field of using modern innovative nanotechnologies in dentistry.

General Background

Theoretical methods were used: analysis, synthesis, and generalisation of literature on the use of nanotechnology in dentistry. The method of comparing nanocomposites with other composite materials was also used. Nanotechnology has been explored in an attempt to improve process and overall performance in dental practice. Therefore, understanding how these materials can be used in our daily practice requires a deeper understanding of the science behind nanotechnology. This article reviews nanomanufacturing applications in the treatment, prosthetics, and preventive care of the oral cavity and teeth.

Data Analysis

Studies by foreign and domestic scientists analyzing the use of innovative nanotechnologies in dentistry from 2019 to 2022 have been included.

The article scrutinizes the application of nanotechnology and intelligent nanomaterials, advances in caries treatment methodologies through nanotechnological interventions, and assesses nanocomposites, which categorize into three distinct classes: metal matrix nanocomposites, ceramic matrix nanocomposites, and polymer matrix nanocomposites. A comprehensive overview of extant literature pertaining to the utilization of nanomaterials and nanopreparations by dental experts is provided.

Results and Discussion

Nanotechnological Advancements in Dentistry

Abduazimova-Ozsujlu et al. (2021) points to innovations in dental practice. Dentistry, as a science, does not stand still, new technologies are developing, new principles of treatment and patient management are being applied. Before moving on to consider innovative nanotechnologies in dentistry, it is necessary to first clarify the term "nanotechnology". The prefix "nano" is adopted in the International System of Units (SI) and corresponds to one billionth of the original unit. For example, a nanometre (nm) is equal to 1-10-9 m. Highly dispersed solid-phase objects whose dimensions range from 1 to 100 nm are called nanoparticles. Capable of self-organisation, they can form agglomerates, clusters, and other ordered structures up to several micrometres (1-10-6 m) in size.

The word "nanotechnology" does not carry any negative or fantastic connotations - it is simply that advances in physics and chemistry have enabled researchers to operate with objects in the nanometre range. Nanotechnology is a branch of science that deals with objects of extremely small size, on the order of a hundred nanometres. The processes of nanotechnology are based on the laws of quantum mechanics and include atomic assembly of molecules, new methods of recording and reading information, local stimulation of physical and chemical reactions at the molecular level, etc. It is believed that the active development of nanotechnology began with a report by Nobel Prize-winning physicist Richard Feynman in 1959. The scientist proposed the method of atomic (molecular) assembly, the essence of which is the manufacture of materials and parts from the elementary constituent elements of matter - atoms or molecules. Dr. Eric Drexler is the author of the concept of nanotechnology, or, as he is called, the "father of nanotechnology". In 1981, he published an article in which he described the basic principles of molecular engineering and the directions of scientific thought on the development of nanotechnology (Song & Ge, 2019). One of the most progressive industries is dentistry, where the latest achievements of science and technology are successfully applied. The development and creation of nanocomputers capable of not only performing quantum computing but also controlling the nanomachines of the future - nanobots - opens up new opportunities for medicine. In the future, nanobots will adapt to the environment by sensing its slightest changes, move as needed, and perform molecular assembly to repair damaged areas, which will provide high potential for the use of these devices for medical purposes, especially in dentistry, where the doctor is faced with the task of not only curing and relieving the patient of pain but also preserving its appearance and functionality to the maximum extent possible. With the advent of this technology in dentistry, the boundaries of possibilities have expanded significantly. The founder of research in the field of nanodentistry was Robert Freitas. In 2000, he published an article about the potential use of nanorobots for orthodontics and dentin regeneration, as well as the use of nanomaterials in oral hygiene products. According to scientist, nanomedicine is the tracking, correction, design, and control of human biological systems at the molecular level using engineered nanoparticles and nanotechnology. The creation of nanomedicine is a matter of the near future; it does not exist yet, but there are rapidly developing technologies that allow us to create unique devices and applications that open up new opportunities and directions in various areas of modern medicine. The global dental community was introduced to the "nanoworld" in autumn 2002 when the first composite material of the new generation, Filtek Supreme nanocomposite, was presented at the International Dental Exhibition in Vienna (Fig. 1). A high degree of filling combined with abrasive wear resistance, good polishability and high aesthetics allowed this subfamily of composites to become a standard restorative material and complete the evolution of inorganic filler sizes from macrofilled to nanohybrid.

Figure 1. Filtek Supreme nanocomposite
Source: (Chávez-Andrade et al., 2019)

In dental practice, nanotechnology has found application at all stages. The ability to deliver the active ingredient directly to the problem area has brought the treatment and prevention of oral diseases to a new level of efficiency.

Currently, nanotechnology is used for:

- in treatment (nanocomposite materials, glass ionomer cement of triple curing, tooth canal fillers based on modified nanocompounds, regenerating agents based on short peptides);
- in prosthetics (elimination of the consequences of periodontal diseases due to the compaction of periodontal tissues and fixation of mobile teeth, implantation of implants through the root of a loose tooth);
- in preventive oral and dental care (toothpaste, gels, and rinses with nanoparticles that have bioantioxidant, anti-inflammatory, and deodorising effects, artificial protective plaque for teeth based on nanotubes).

Nanoparticles are able to pass through biological barriers, carrying the necessary molecules precisely to the intended target (Table 2).

Table 2.
Nanoparticle types and their applications in medicine

Liposomes	(nanospheres of aqueous substance enclosed in a lipid membrane) are unique carriers of medicinal substances
Ceramic nanoparticles	are often used as drug carriers in the treatment of tumours
Iron oxide nanocrystals	can be used in the diagnosis of diseases using magnetic resonance methods
Composite shells	are used as drug carriers
Silver nanocrystals	are used for the topical treatment of infected skin wounds
Fullerenes (a new allotropic form of carbon)	have their own biological activity, exhibiting antioxidant properties
Carbon nanotubes	are a plane rolled into a cylinder and are of great interest as drug carriers with controlled release capabilities
Quantum particles	are used in the diagnosis of tumours and other diseases

Source: (Moradpoor et al., 2021)

Japanese scientists have used advanced nanotechnology to create a material called nanocrystalline medical hydroxyapatite (nano-mHA). This artificially synthesised material is completely similar to natural hydroxyapatite (or calcium hydroxide phosphate), the main mineral in bone and hard tooth tissue. It consists of 97% tooth enamel and 70% tooth bone. The health and beauty of teeth depends on the condition of the enamel, which protects the tooth from external factors. The enamel of a healthy tooth is translucent, its natural colour is close to the colour of ivory. However, under the influence of the environment, diet and individual characteristics of the body, teeth lose their supply of valuable hydroxyapatite, the enamel becomes covered with plaque and stains, dull and cloudy, tooth sensitivity increases and caries develops. One of the most effective methods of its prevention and treatment is nanotechnology (Amissah et al., 2021). Ensuring the timely supply of the required amount of minerals to the tooth tissue can prevent the development of caries at an early stage. The ability of tooth tissue to regenerate is provided mainly by hydroxyapatite. In the process of remineralisation, new hydroxyapatite crystals are formed. Medical nano-hydroxyapatite is designed to solve the problem of restoring the structure of tooth tissue (Blinova & Rumyantsev, 2021). The nanoscale form of hydroxyapatite was developed by Japanese researchers who have been studying this problem since 1978. Today, thanks to the development of nanotechnology, the improved formula of nano-mHAP consists of two-dimensional nanoparticles - on average 50 nanometres instead of nanoparticles. Particles with a size of 300 nanometres were used previously (1 nanometre = 1 millionth of a millimetre). This has significantly increased the restorative properties of nanohydroxyapatite when acting on tooth enamel and bone tissue (Moradpoor et al., 2021). During toothbrushing, hydroxyapatite nanoparticles are incorporated into tooth tissues and repair microscopic defects and enamel damage. The ability of nano-mHA to form strong bonds with proteins leads to the destruction of plaque and its effective removal (Martin et al., 2019). As a result, the enamel becomes smooth and more resistant to bacteria. A standard oral hygiene kit can only act superficially. Products with nanoscale components are able to penetrate deeply into the organs and tissues of the oral cavity. This makes it possible and significantly increases the effectiveness of the impact on the roots of the teeth and gum layers. For example, for the most effective remineralisation of teeth, hydroxyapatite particles are added to toothpaste and gels. Thanks to these particles, the rate of tooth enamel restoration is significantly increased (Sun et al., 2019).

Nowadays, the drug “VIVAX Dent” has proven itself well, offering a number of therapeutic and prophylactic agents, including:

– balms-rinse containing a complex of amino acids, aloe vera;
– anti-inflammatory toothpaste containing a complex of amino acids, with bisabolol, with betulavit;
– gel with bioantioxidant and amino acid complex Neovitin (Tong et al., 2019).

A study by American scientists from the University of Texas Health Science Centre at San Antonio has shown that nano-hydroxyapatite not only prevents caries but can also eliminate caries at an early stage. This is due to the ability of nano-mHAP ions to penetrate the microscopic spaces between the enamel prisms, integrating into the crystal lattice of tooth enamel hydroxyapatite crystals. Due to its biocompatibility and bioactivity, nanohydroxyapatite, unlike fluoride, which has toxic properties, does not add anything “foreign” to tooth enamel. It naturally ensures the supply of minerals to the tooth tissues and restores the enamel structure.

The ability of nanomaterials to reproduce the mechanical, physicochemical, and aesthetic properties of dentin and tooth enamel is a significant advantage for their use in dental restoration (Ali Sabri et al., 2021). Some of the composite materials used in dentistry today are nanomaterials, which include ceramics, silicon, sapphire, or even diamond nanoparticles. Such materials are similar to natural teeth in terms of aesthetics, but they are significantly superior in terms of strength and hardness.

The advantage of nanomaterials over traditional composites is primarily due to the optical properties of nanoparticles, their better polishing ability, and the preservation of the polished surface for a long time. There are two main types of dental composite materials containing nanoparticles: nanocomposites and nanohybrids, which differ in the size of the particles they contain. Thus, nanohybrid composites include fillers of different sizes, for example, large glass particles (on average, about 2000 nm) mixed with particles of about 10 nm, and nanocomposites contain particles of more uniform size (particles of about 75 nm are mixed with particle sizes from 5 to 25 nm) (Loyola-Rodríguez et al., 2019). The advantages of nanoscale fillers are increased wear resistance, reduced shrinkage, reduced shrinkage stresses, better polishability, more pronounced gloss, and special fillers. The mechanical strength of true nanocomposites is comparable to that of the best microhybrid composites. On the other hand, nanocomposites are highly aesthetically pleasing (Valerio et al., 2019). Liquid nanocomposites are widely used in medical practice. Improved strength and aesthetic characteristics make it possible to use these materials in situations that previously required long and labour-intensive treatment.

In dentistry, nanocomposites are being actively introduced into the technology of replacing wedge-shaped tooth defects, for minimally invasive filling of carious lesions, direct and indirect dental restoration, etc. It can be noted that nanocomposites have a small particle size and are universal in use, unlike macrofilled, microfilled, and hybrid composites. In terms of their positive properties, nanocomposites are superior to composite materials. For example, while macrofilled composites have only high strength, nanocomposites are easy to polish, have low shrinkage, are highly aesthetic and colourfast (Omanović-Mikličanin et al., 2020) Nanocomposites have practically no negative qualities (except for the high cost of the material), which cannot be said about other composite materials (Table 3).

Table 3.
Comparative characteristics of nanocomposites with other composite materials

	Macro-filled	Micron-filled	Hybrid	Nanocomposites
Particle size	1-100 microns	0.007 - 0.4 µm	0.04 - 5 microns	Nanocluster up to 1 µm
Average particle size	5-30 microns	0.2 µm	1 micron	20 - 75 nm
Filler content by weight (%)	75-85	36-79	75-87	78.5 nm
Indications	Loaded cavities of 1.2 classes; cavities of 5 classes in unaesthetically important areas; superstructure of the tooth stump for artificial crowns.	Restoration of anterior teeth without high load; cosmetic contouring of macrophylls	Universal, but in some cases of restorations are not always effective in cavities of classes 2, 4, 5. (Not ideal filling surface)	Universal, used for filling all groups of teeth and classes of cavities, correcting the anatomical shape and colour of teeth.
Positive properties	High resistance	Aesthetics; excellent polish; uniform wear of the matrix and filler.	Acceptable aesthetic properties; sufficient strength; the quality of the filling surface is better than that of macrofilled composites.	Highly durable; colour stable; easy to polish; highly aesthetic; antagonists do not erase; low shrinkage (2.2%).
Negative properties	High roughness; poor polish; unaesthetic appearance; discolouration; secondary caries; high abrasiveness.	Low resistance	Not ideal surface quality (worse than microfilled composites); insufficient polish, low dry gloss resistance.	Material cost

Source: (Reduwan Billah, 2019; Abd El-Fattah et al., 2021)

The inception of nanocomposite technology in the dental market occurred during the Vienna trade fair in October 2002, when 3M ESPE introduced their pioneering product. This breakthrough was the culmination of extensive and protracted research efforts dedicated to the development of the revolutionary 3M ESPE Filtek Supreme dental filling material, which incorporated a nanofiller component (3M ESPE, 2010). In the context of nanocomposite materials, a fundamental distinction exists between "true" nanocomposites and nanohybrid composites. "True" nanocomposites are characterized by their composition comprising exclusively of nanoparticles and nanoclusters. The technology employed in nanohybrid composites entails the integration of nanoparticles into conventional filler matrices. A "true" nanocomposite filler, for instance, combines unbound silicon nanoparticles measuring 20 nm in size, as well as zirconia particles with dimensions ranging from 4 to 11 nm. Additionally, these materials contain agglomerated clusters comprising 20 nm silicon particles and 4-11 nm zirconia particles. This amalgamation of nanoparticles and nanoclusters within a single material result in a material characterized by a remarkable degree of homogeneity, exceeding 75%, thereby affording it substantial mechanical strength. Notable representatives of "true" nanocomposite materials in this category include Filtek Supreme and Filtek Supreme XT, both manufactured by 3M ESPE (Jandt & Watts, 2020). Nanocomposites are easily and quickly polished to a “dry” mirror shine and retain this shine for a long time. This is due to the fact that under conditions of abrasive wear, as the organic matrix wears away, only individual nanoparticles that are not “recognised” by a beam of visible light are detached from the clusters. The material has low shrinkage (2.2%) due to the use of high molecular weight resins Bis-GMA, UDMA, Bis-EMA in the organic matrix. Low shrinkage ensures good edge adhesion of the material, allows the material to be introduced into the cavity in horizontal layers and non-directional polymerisation. The small particle size also provides high transparency and opalescence (“milky”) colour. In dentistry, opalescence can be defined as the level of yellow light passing through the filling compared to the level of blue light reflected (when looking at the filling in front of a black background). This effect is called “Rayleigh colour scattering” in honour of the 19th-century physicist Baron Rayleigh. The effect is as follows: when light hits a filler particle, it is either absorbed or scattered. When white light hits very fine particles, it scatters red, yellow, and green colours in the forward direction, while blue rays are reflected in the opposite direction. This effect explains the “chameleon” effect or the imperceptible transition of the filling into the surrounding tooth tissue, as the effect of multiple light scattering occurs. The nanocomposite has the property of plasticity, which makes it possible not to stick to the working part of the instrument. Quick gloss and long-term preservation, high strength - all this makes the material versatile (Kolenko & Lytvyn, 2019; Jiao et al., 2021). The use of nanotechnology in implantology is possible by applying nanoparticles to the surface of implants that can control the processes of protein adsorption, cell differentiation, and adhesion. For example, biologically active calcium phosphate nanocrystals applied to titanium implants stimulate the process of osseointegration, which significantly increases the long-term effectiveness of implantation (Naik et al., 2020). Therefore, nanotechnologies that modify the surface of dental implants are increasingly used today. The future of dentistry in this area is seen in the synthesis of the use of nanotechnology and the biomimetic approach (biomimetics are products that mimic the natural structure and properties of biological materials), ensuring that they can be used to restore damaged enamel, taking into account the biological response. To date, several types of nanocoatings for dental implant surfaces have been developed: diamond coating, hydroxyapatite coating, and metal-ceramic coating. Only a few manufacturers produce implants with nanoparticle surface treatment. A number of laboratory and preclinical studies have shown that the results of fixation of implants with a nanomodified surface are significantly higher compared to conventional implants (Vasiliu et al., 2021; Pinto et al., 2019). However, to date, there have been no large randomised clinical trials that could confirm the high survival rate and durability of implants with a nanoparticle-treated surface. The most well-known manufacturers of dental products using nanotechnology are Nobel Biocare, Dentsply Sirona, Straumann, 3M, Danaher, Ivoclar, Heraeus Kulzer, and Zimmer Biomet Dental. The companies are actively investing in the development of projects related to the nanomodification of dental implant surfaces to maintain high sales volumes in the market in the future (Ismailov et al., 2022; Makonin et al., 2022; Xu et al., 2019). According to expert reports, the demand for implants with nanomodified surfaces will increase in the coming years due to the results of studies confirming the benefits of this product. Sales will also be boosted by the growing number of elderly people with adentia in Western countries and rising incomes in Asia, Africa, and South America. In addition, the medical community is widely promoting the importance of maintaining healthy teeth and gums and the link between oral diseases and other systemic diseases. All these factors will lead to the growth of sales of nanocoated implants in the market. Currently, the majority of sales are in Europe and North America, with progressive growth observed after the economic crisis of 2009. Representatives of Straumann said that the first research in the field of nanotechnology for dentistry began in 2010. The first works of the company's specialists were published in 2012 and 2013. SLActive implants are actively installed in Europe, North and Latin America, and in 40 countries in the Asia-Pacific region. The largest number of sales are in Europe, the USA, Brazil and Japan. To date, more than 6.5 million implants have been sold.

Nobel Biocare produces Xeal nanostructured abutments, which are sold in Europe, Canada, Hong Kong, Australia and New Zealand, Croatia, Turkey, Greece, India, and Vietnam. Nobel Biocare has been developing Xeal and TiUltra anodised surfaces for 5 years. Clinical studies of the products were published in 2019 and will continue for several more years.

Thus, it is obvious that modern technologies are actively used to develop products that are widely used by dentists. For example, according to representatives of Nobel Biocare, the most popular products are implants with new surfaces - NobelActive and NobelParallel.

Currently, three-dimensional printing (3D printing) technology is being used in many industries, using special 3D printers. Such 3D printing has found application in digital dentistry, which has become possible thanks to its active implementation by orthopedic doctors. This technology makes it possible to manufacture dentures, bypassing the labour-intensive costs associated with making an impression of the jaw, casting a plaster model of it, manufacturing dentures, fitting dentures to an artificial (model) jaw, and then fitting dentures to the patient's jaw. To overcome these difficulties in dentistry, 3D printers are used to make dentures, which are much more efficient and productive than conventional milling machines used in dentistry. The 3D printer produces moulds for casting teeth, as well as teeth and crowns themselves, not only quickly and efficiently, but, most importantly, taking into account the anatomical features of the patient's oral cavity (Naik et al., 2020; Tavares et al., 2021).

Challenges and Dilemmas in Dental Implantation

Despite the widespread use of nanotechnology, in some cases, it can carry certain risks. Nanomaterials are highly active and permeable to the skin, lungs, and digestive tract. Therefore, the constant use of such materials can lead to their penetration through the bloodstream to various organs and further accumulation in the organs. This can result in inflammatory processes and even gene mutations.

But the impact of nanoparticles on the body remains unexplored. In addition, it is difficult to separate the effects of nanoparticles from other factors that affect clinical outcomes. The release of particles into the bloodstream is considered a risk factor for the inflammatory process. However, to date, there is no scientifically proven evidence of the negative impact of nanoparticles.

The physical and chemical properties of nanoparticles vary depending on their origin and can have different effects on living organisms. The study of the cytotoxicity of particles formed during the destruction of nanocomposite materials has emerged as an urgent problem in recent years along with the development of nanotechnology and the widespread use of nanocomposites in the medical industry. Nanoparticles penetrate into cells by endocytosis and are contained within endocytic bubbles. The apoptogenic effect of silicon nanoparticles is associated with both cytotoxic effects, such as increased lipid peroxidation and subsequent damage to the plasma membrane, and genotoxic effects, such as chromosomal aberrations during mitosis. For example, silicon nanoparticles with diameters of 14-, 15-, and 16-nm have a toxic effect (TC(50)) at a concentration of 33-47 μg/cm-2, and nanoparticles with diameters of 19 and 60 nm - at a concentration of 89 and 254 μg/cm-2, respectively. Thus, silicon oxide has size-, dose-, and time-dependent cytotoxicity. At the same time, smaller particles exhibit significantly greater cytotoxicity than larger particles. In the modern literature, information on the toxicity of silica is increasingly found. There are numerous studies proving the cytotoxic effect of silica nanoparticles when they enter the respiratory system from production.

Despite the fact that all restorative materials used in hospitals are certified and recommended for filling carious cavities of all classes, there are still a number of questions about limiting the use of nanocomposites on those tooth surfaces where abrasion and accumulation of nanoparticles occurs more rapidly.

Potential Solutions and Future Directions

In April 2017, the European Parliament introduced rules on the use of medical devices, including nanotechnology. They raised the issue of the need to create a single description of all nanomaterials to ensure their safe use and the legitimate use of materials by manufacturers. The Regulation introduced the concept of nanomaterials as natural, recycled, or manufactured materials containing particles in a free or bound state, 50% or more of which have an external dimension of 1 to 100 nm.

However, ISO standards for nanomaterials have not yet been fully developed, so laboratory and clinical studies are required before a new product can be marketed. In addition to safety concerns, the production of nanomaterials poses a number of other challenges: engineering, biological, and social. Firstly, due to their tiny size, it is difficult to arrange the particles correctly according to a given plan. Secondly, nanomaterials are pyrogenic, which causes environmental problems. The third problem is how society will perceive new types of materials. To indicate the use of nanocomposites for single-patient volumetric restorations, additional fundamental studies of the biocompatibility and biosafety of modern nanocomposite materials are needed. However, when assessing the biosafety of a nanocomposite material, the types of cells analyzed, the conditions of exposure of nanoparticles to cells, and cytotoxicity assays should be taken into account.

The introduction of new nanocomposite materials into practical medicine requires fundamental research on their biosafety. The use of such materials can have different effects on different cells, tissues, organs, and the human body as a whole. For example, the universal restorative material 3MTMESPETMFiltekTMUltimate is recommended by manufacturers for filling anterior and posterior groups of teeth (including occlusal surfaces), for core augmentation, splinting, and indirect restorations, including inlays, onlays, and veneers. However, given the possible negative impact of nanocomposite particles released during abrasion on body cells, we consider it advisable to limit the use of the material on occlusal surfaces, since in this area restorations are subjected to greater mechanical stress and wear out faster.

Conclusions

The letter combination “nano” should no longer surprise a modern dentist. Even at the beginning of the 21st century, nanotechnology was a relatively new page in the intellectual epic novel that humanity is writing. Today, fundamental theoretical knowledge is being actively integrated into applied fields of science and technology, and nanomaterials are becoming a common attribute of daily dental practice. An important role in the development of nanotechnology in dentistry is played by the development of new nanomaterials that can meet the necessary properties and requirements. A review of research on the properties of nanomaterials allows us to assess the prospects for the use of nanotechnology in dentistry. Dental nanomaterials are a new area of research, the benefits, and risks of which are still unknown. Long-term clinical trials are required to evaluate them. Nevertheless, implants with a nanomodified surface will become increasingly popular over time due to the current outstanding results of their placement. The large number of elderly people with adentia and the growing prosperity of the population in some regions of the world will lead to an increase in sales of such products. Some researchers argue that nanotechnology has reached such a level that in the future it will be possible to fully restore damaged teeth. Let's wait, maybe this incredible idea will become a reality someday.

Some scoffers say that at this rate, dentists will soon not be needed. In fact, any process must be managed by a highly qualified specialist. Without him, all supertechnologies are like a computer in the hands of a Neanderthal - a pile of scrap metal.

Suggestions for Future Research

The integration of novel nanocomposite materials into clinical dentistry necessitates comprehensive investigation into their biocompatibility. These materials may induce varying effects on distinct cells, tissues, organs, and the overall human physiological system. Considering the potential adverse consequences associated with the release of nanocomposite particles during wear and tear, it is prudent to exercise caution and restrict the application of such materials to occlusal surfaces. This decision is rooted in the fact that restorations in this region experience heightened mechanical stresses and consequently exhibit accelerated wear and tear. Additional investigation is required to elucidate the mechanisms of nanomaterial exposure, evaluate their potential toxicity and risk to human health. Assessing the danger posed by nanoparticles and nanomaterials to the human organism demands the creation of innovative and potentially distinctive methodologies. These methodologies must consider factors such as size, shape, methods of stabilization, modification, and alterations in their movement within both the environment and the human body.

Bibliographic references

3M ESPE. (2010). *Filtek™ Z350 XT Universal Restorative System*. https://acortar.link/p9tLPu

Abd El-Fattah, A., Youssef, H., Gepreel, M. A. H., Abbas, R., & Kandil, S. (2021). Surface Morphology and Mechanical Properties of Polyether Ether Ketone (PEEK) Nanocomposites Reinforced by Nano-Sized Silica (SiO_2) for Prosthodontics and Restorative Dentistry. *Polymers*, 13(17), 3006. https://doi.org/10.3390/polym13173006

Abduazimova-Ozsujlu, L. A., Muhtorova, M. M., Abduazimov, A. A., Hanazarov, D. A., & Mazifarova, K. R. (2021). Problems of innovative education in medicine. *Bulletin of Science and Education*, 15-2(118), 50-56. https://acortar.link/pYz4Sj

Ali Sabri, B., Satgunam, M., Abreeza, N. M., & Abed, A. (2021). A review on enhancements of PMMA Denture Base Material with Different Nano-Fillers. *Cogent Engineering*, 8(1). https://doi.org/10.1080/23311916.2021.1875968

Amissah, F., Andey, T., & Ahlschwede, K. M. (2021). Nanotechnology-based therapies for the prevention and treatment of Streptococcus mutans-derived dental caries. *Journal of Oral Biosciences*, 63(4), 327-336. https://doi.org/10.1016/j.job.2021.09.002

Blinova, A. V., & Rumyantsev, V. A. (2021). Nanomaterials in the modern dentistry (review). *Dentistry*, 100(2), 103. https://doi.org/10.17116/stomat2021100021103

Chávez-Andrade, G. M., Tanomaru-Filho, M., Basso Bernardi, M. I., de Toledo Leonardo, R., Faria, G., & Guerreiro-Tanomaru, J. M. (2019). Antimicrobial and biofilm anti-adhesion activities of silver nanoparticles and farnesol against endodontic microorganisms for possible application in root canal treatment. *Archives of Oral Biology*, 107(104481), 104481. https://doi.org/10.1016/j.archoralbio.2019.104481

Ismailov, F. R., Khabadze, Z. S., Generalova, Y. A., & Bakaev, Y. A. (2022). Optimizing root canal obturation. *Endodontics Today*, 20(2), 131-135. https://doi.org/10.36377/1726-7242-2022-20-2-131-135

Jandt, K. D., & Watts, D. C. (2020). Nanotechnology in dentistry: Present and future perspectives on dental nanomaterials. *Dental Materials: Official Publication of the Academy of Dental Materials*, 36(11), 1365-1378. https://doi.org/10.1016/j.dental.2020.08.006

Jiao, C., Sun, L., Shao, Q., Song, J., Hu, Q., Naik, N., & Guo, Z. (2021). Advances in waterborne acrylic resins: Synthesis principle, modification strategies, and their applications. *ACS Omega*, 6(4), 2443-2449. https://doi.org/10.1021/acsomega.0c05593

Khademi, S., Sarkar, S., Shakeri-Zadeh, A., Attaran, N., Kharrazi, S., Ay, M. R., Azimian, H., & Ghadiri, H. (2019). Targeted gold nanoparticles enable molecular CT imaging of head and neck cancer: An in vivo study. *The International Journal of Biochemistry & Cell Biology*, 114(105554), 105554. https://doi.org/10.1016/j.biocel.2019.06.002

Kolenko, Yu., & Litvin, T. (2019). The use of modern innovative nanotechnologies to perform highly aesthetic dental restorations. *Suchasna stomatology*, 3, 18-22. Retrieved from http://ir.librarynmu.com/bitstream/123456789/900/1/kolenko_3-2019.pdf

Lamster, I. B. (2021). The 2021 WHO resolution on oral health. *International Dental Journal*, 71(4), 279-280. https://doi.org/10.1016/j.identj.2021.06.003

Loyola-Rodríguez, J. P., Torres-Méndez, F., Espinosa-Cristobal, L. F., García-Cortes, J. O., Loyola-Leyva, A., González, F. J., Soto-Barreras, U., Nieto-Aguilar, R., & Contreras-Palma, G. (2019). Antimicrobial activity of endodontic sealers and medications containing chitosan and silver nanoparticles against *Enterococcus faecalis*. *Journal of Applied Biomaterials & Functional Materials*, 17(3), 228080001985177. https://doi.org/10.1177/2280800019851771

Makonin, A. V., Kopetskiy, I. S., Nikolskaya, I. A., Pobozhieva, L. V., Shevelyuk, J. V., Khritova, A. A., & Shalaev, I. A. (2022). Analysis of the marginal adaptation of temporary filling materials to tooth tissues. *Endodontics Today*, 20(2), 121–125. https://doi.org/10.36377/1726-7242-2022-20-2-121-125

Martin, V., Ribeiro, I. A. C., Alves, M. M., Gonçalves, L., Almeida, A. J., Grenho, L., Fernandes, M. H., Santos, C. F., Gomes, P. S., & Bettencourt, A. F. (2019). Understanding intracellular trafficking and anti-inflammatory effects of minocycline chitosan-nanoparticles in human gingival fibroblasts for periodontal disease treatment. *International Journal of Pharmaceutics*, 572(118821), 118821. https://doi.org/10.1016/j.ijpharm.2019.118821

Moradpoor, H., Safaei, M., Mozaffari, H. R., Sharifi, R., Imani, M. M., Golshah, A., & Bashardoust, N. (2021). An overview of recent progress in dental applications of zinc oxide nanoparticles. *RSC Advances*, 11(34), 21189-21206. https://doi.org/10.1039/d0ra10789a

Naik, N., Pai, S., Bhat, V., Patil, V., Awasthi, S., & Nayak, N. (2020). Numerical three-dimensional finite element modeling of cavity shape and optimal material selection by analysis of stress distribution on class V cavities of mandibular premolars. *Journal of International Society of Preventive & Community Dentistry*, 10(3), 279. https://doi.org/10.4103/jispcd.jispcd_75_20

Ni, C., Zhou, J., Kong, N., Bian, T., Zhang, Y., Huang, X., Xiao, Y., Yang, W., & Yan, F. (2019). Gold nanoparticles modulate the crosstalk between macrophages and periodontal ligament cells for periodontitis treatment. *Biomaterials*, 206, 115-32. https://doi.org/10.1016/j.biomaterials.2019.03.039

Omanović-Mikličanin, E., Badnjević, A., Kazlagić, A., & Hajlovac, M. (2020). Nanocomposites: a brief review. *Health and Technology*, 10(1), 51-59. https://doi.org/10.1007/s12553-019-00380-x

Pinto, C. L., Bhering, C. L. B., de Oliveira, G. R., Maroli, A., Reginato, V. F., Caldas, R. A., & Bacchi, A. (2019). The influence of post system design and material on the biomechanical behavior of teeth with little remaining coronal structure. *Journal of Prosthodontics: Official Journal of the American College of Prosthodontists*, 28(1). https://doi.org/10.1111/jopr.12804

Reduwan Billah, S. M. (2019). Composites and Nanocomposites. In *Polymers and Polymeric Composites: A Reference Series* (pp. 1–67). Springer International Publishing. ISBN: 978-3-319-92067-2

Song, W., & Ge, S. (2019). Application of antimicrobial nanoparticles in dentistry. *Molecules (Basel, Switzerland)*, 24(6), 1033. https://doi.org/10.3390/molecules24061033

Sun, X., Wang, L., Lynch, C. D., Sun, X., Li, X., Qi, M., Ma, C., Li, C., Dong, B., Zhou, Y., & Xu, H. H. K. (2019). Nanoparticles having amphiphilic silane containing Chlorin e6 with strong anti-biofilm activity against periodontitis-related pathogens. *Journal of Dentistry*, 81, 70–84. https://doi.org/10.1016/j.jdent.2018.12.011

Tavares, S. J. O., Gomes, C. C., Marceliano-Alves, M. F., Guimarães, L. C., Provenzano, J. C., Amoroso-Silva, P., Machado, A. G., Siqueira, J. F., Jr, & Alves, F. R. F. (2021). Supplementing filling material removal with XP-Endo Finisher R or R1-Clearsonic ultrasonic insert during retreatment of oval canals from contralateral teeth. *Australian Endodontic Journal: The Journal of the Australian Society of Endodontology Inc*, 47(2), 188–194. https://doi.org/10.1111/aej.12451

Tong, Z., Zhang, Y., & Wei, X. (2019). The effect of human serum and dentin powder alone or in combination on the antibacterial activity of sodium hypochlorite against Enterococcus faecalis. *Archives of Oral Biology*, 97, 72-76. https://doi.org/10.1016/j.archoralbio.2018.10.008

Valerio, M. S., Alexis, F., & Kirkwood, K. L. (2019). Functionalized nanoparticles containing MKP-1 agonists reduce periodontal bone loss. *Journal of Periodontology*, 90(8), 894-902. https://doi.org/10.1002/jper.18-0572

Vasiliu, S., Racovita, S., Gugoasa, I. A., Lungan, M.-A., Popa, M., & Desbrieres, J. (2021). The benefits of smart nanoparticles in dental applications. *International Journal of Molecular Sciences*, 22(5), 2585. https://doi.org/10.3390/ijms22052585

Xu, Y., Wang, C., Hou, J., Wang, P., You, G., & Miao, L. (2019). Effects of cerium oxide nanoparticles on bacterial growth and behaviors: induction of biofilm formation and stress response. *Environmental Science and Pollution Research International*, 26(9), 9293-9304. https://doi.org/10.1007/s11356-019-04340-w

Xue, Y., Hong, X., Gao, J., Shen, R., & Ye, Z. (2019). Preparation and biological characterization of the mixture of poly(lactic-co-glycolic acid)/chitosan/Ag nanoparticles for periodontal tissue engineering. *International Journal of Nanomedicine*, 14, 483-498. https://doi.org/10.2147/ijn.s184396

Zafar, M. S. (2020). Prosthodontic applications of polymethyl methacrylate (PMMA): An update. *Polymers*, 12(10), 2299. https://doi.org/10.3390/polym12102299