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Nanotechnology in Dentistry – Current State and Future Perspectives

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SUMMARY

Nanotechnology has been considered as multidisciplinary field of scientific research about different types of nanoparticles as well as the application of new nanomaterials and nanodevices in numerous areas of human interest. It offers advances in industry, engineering, information and communication technology, electronics, environmental science and energy savings, economics etc. New nanoproducts and nanotehnology could be applied in almost all fields of human activity. Potential benefit of nanomaterials and nanorobots applied in medicine and dentistry is of main concern when thinking about nanoadvances. However, nanotechnology has become a controversial issue between scientific and public opinions due to the insufficient knowledge of potential hazard to human health and environment. Some of the raised questions are what are the advantages and disadvantages of nanotechnological evolution, and what kind of future can be expected when changes gain wider scale? The aim of this study was to present the importance of nanotechnology in various areas, especially in medicine and dentistry, and to point out possible consequences of their use to human health and environment.

Keywords: nanotechnology; nanomaterials; dentistry

INTRODUCTION

The universal definition of nanotechnology has not been established yet, since the existing definitions vary depending on the intended use. Therefore, current attempts to define nanotechnology can be divided in the three main groups: scientific definitions, public definitions and those that allow making certain decisions [1].

Nanotechnology is the science and engineering involved in design, synthesis, characterization and application of materials and devices whose smallest unit of measurement in at least one dimension is on the nanometer scale (one billionth of a meter, 10^{-9} m) [2]. This means that what we consider nanomaterial or a nanodevice, has the smallest dimension of about 100 nm i.e. maximum 1×10^{-7} m. For comparison, the diameter of human hair is about 50 µm and it is 50,000 times larger than the size of 1 nm [3]. Further, the average diameter of the bacterium *Streptococcus mutans* 10 449 is around 0.321±0.007 µm [4], while the size of a hydrogen atom is in the range of 0.1 to 0.2 nm [5].

Nanotechnology and the science of nanomaterials have a potential to provide benefits in numerous areas such as synthesis of new materials with advanced properties, production technology, information technology and electronics, ecology and energy conservation, nanobiosystems, medical appliances, transportation, economy, etc. It is unlikely that there is any segment of human life and activity in which nanotechnology cannot be applied. It is also estimated that nanotechnology will affect the psychology of people as well as their understanding of the world they live in (social phenomena, philosophical views and ethical considerations) [6, 7, 8].

According to the U.S. National Institutes of Health, nanomedicine includes the application of nanotechnology in a "very specific medical intervention at the molecular level, i.e. to treat disease and repair damaged tissue such as bones, muscles and nerves." Johnson and McGee [9] maybe defined nanomedicine more appropriate as "nanomedicine involves medical interventions that use materials, machines and mechanisms created or controlled by nanoscience and nanotechnology in order to monitor, improve or maintain health". Accordingly, the potential applications of nanotechnology in medicine are drug and genetic material delivery (viral vectors, non-viral vectors, such as nanoparticles, liposomes, or dendrimers and so-called "gene guns"), imaging, molecular diagnosis, therapy, cardiology, orthopedics, etc. [2, 10-13].

Most of nanotechnology applied in medicine, can also be applied in dentistry. Nanodentistry has a potential to improve oral health by providing sophisticated preventive, diagnostic and therapeutic measures using nanomaterials, biotechnology and nanorobots [14]. That way, advanced dental care could be delivered throughout the world population [2, 15].

The structure of material that has particles of a nanometer size possesses special properties. Physical and chemical properties of materials become quite different when number of constitutional atoms is greatly reduced. A small number of atoms allow different positioning and distance

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between them making those properties to be dominant physical and chemical properties of the object [5, 16].

EARLY VISION

At the annual meeting of the American Physical Society, back in 1959, the physicist and Nobel laureate Richard P. Feynman has drawn great attention of the scientific community by his revolutionary statement that "there is a plenty of room at the bottom." He talked about future possibility to create materials and devices at the atomic or molecular level and by his speech he has influenced human mind to conceive an innovative way of thinking. He suggested that the existing machinery and equipment should produce smaller tools which would than produce even smaller machines and tools and so on, up to the molecular level. He suggested that nanomachines, nanorobots and nanodevices could be ultimately used to develop a wide range of atomically precise microscopic instruments and production tools. Its historical lecture Feyman concluded with words: "This is a developmental path that cannot be avoided "[17, 18].

CURRENT STATE AND FUTURE PERSPECTIVES IN DENTISTRY

Nanotechnology offers a broad range of innovations and improvements in prevention, diagnostics and treatment of oral diseases. The characteristics of composite filling materials have been constantly improved. The mode for producing filler particles for composite materials has been changed on nanotehnological level in order to produce particles smaller than 100 nm. Traditional process for the production of small particles has been characterized by grinding larger pieces of glass, quartz or ceramics, i.e. approach "from the top to the bottom" ("top-down" approach). In order to produce particles smaller than 100 nm, that method has been replaced by chemical processes of direct molecular synthesis and bonding (direct molecular assembly) i.e. applying the approach "from the bottom to the top" ("bottom up" approach). Nanofilled composite systems have shown better physical properties including compressive strength, tensile strength, impact strength, flexural strength and abrasion resistance, etc. than traditional composites filled with microparticles [5]. In addition, aesthetic properties of nanomaterials are superior as compared to traditional, primarily due to the optical properties of nanoparticles as well as better polishability and maintaining polished surface for long time [5]. There are two main types of dental composites filled with nanofillers: nanohybrids and nanofilled. Nanohybrid composites contain fillers of different size e.g. larger glass particles (average size about 2000 nm) mixed with particles of a size around 10 nm, while nanofilled have more uniform particle size e.g. particle size of about 75 nm mixed with particles of sizes from 5 to 25 nm. Nanofilled composite materials are characterized by the combination of nanoparticles and "nano-cloud" (nanoclusters) introduced in Filtek Supreme (3M ESPE). These materials exhibit improved mechanical and physical properties as compared to the conventional composite materials for dental fillings [19].

In the future, nanotechnology and biomimetic approach (biomimetics – mimicking the natural structure and properties of biological materials), could be used for repair and restoration of damaged enamel [20]. Chen et al. [21] have synthesized hydroxyapatite nano-rods which have a structure similar to the enamel prisms (enamel-prism-like hydroxyapatite nanorods). These hydroxyapatite nano-rods possess a feature so called self-connection and switching (self-assembly) and may become nano-restoration that mimic naturally occurring processes, and as such, could be used to restore tooth structure. Similar nano-structures that could also be used for the restoration of tooth substance are nanospheres; genetically engineered peptides that bind to the surface of inorganic materials (GEPIs – genetically engineered peptides for inorganics), amelogenin-based materials as well as restorations that release fluoride [19, 22, 23].

There are number of published papers that have studied possibilities for dental caries prevention of using the benefits of nanotechnology [20, 24-27]. In this studies, nanomaterials have been synthesized and tested. For example, biphasic calcium fluoride/fluorinated hydroxyapatite (CF/FHAp) nanocrystals have been synthesized, characterised and in vitro tested as potential dental filling material with ability to prevent dental caries by fluoride ion release [24]. Also, Min et al. [25] in an *in vitro* study presented the application of hydroxyapatite nanoparticles which, if added to soft drinks for athletes, could prevent teeth erosion. Furthermore, Kim et al. [26], in laboratory conditions, tested the effect of nano-carbonate apatite (n-CAP) in the prevention of late discoloration of teeth after bleaching. They found that 10% n-CAP can substantially maintain achieved color after whitening and provide adequate recovery of tooth enamel.

Based on the current knowledge, it is certain that nanotechnology has a great potential for prevention of dental caries. Tschoppe et al. [27] found in their study that toothpaste and preparations for the caries prevention that contain nano-hydroxyapatite (n-HAp) can enhance the process of remineralization in enamel and dentin. In an in vitro study, they compared the effect of toothpaste with added n-HAp or zinc-carbonate/nanohydroxyapatite ($ZnCO_3$/n-Hap) particles with conventional fluoride toothpastes on bovine enamel and dentin remineralization. They found similar or better effects when used toothpaste with nanoparticles [27].

In the sphere of dental implantology that is making steady progress, further improvement is possible by modifying the surface of endosseous implants with nanoscale surface modification techniques. Such altered properties of nanosurfaces affect cell adhesion, proliferation, and differentiation. The process of osseointegration could be better and faster using that type of surface modification. There are already a few commercial nano-modified dental implant systems available for clinical use [28]. Time will show strengths and weaknesses of dental implants surface modifications through long-term clinical evaluation.

Some promising results using nanotechnology modification have already been obtained in one of the most popular areas in dentistry, guided tissue and periodontal regeneration [29]. New materials with addition of nanoparticles should serve as a scaffold for tissue ingrowths to improve the ability of tissue regeneration. Srinivasan et al. [29] found that experimental alginate/nano-bioactive glass ceramic composite scaffolds could be useful in periodontal regeneration. Such structure provides good protein adsorption and cell adhesion and proliferation.

Although modern protocols for the treatment of pulp diseases and apical periodontitis guarantee high success rates, a new approach in endodontic therapy, which would be also the ideal therapy, is the induction of healthy tissue and replacment of diseased or necrotic pulp tissue. Fioretti et al. studied the anti-inflammatory effects of biologically active nanostructured multilayer films on fibroblasts [30]. They reported first time use of these films containing melanocortin peptides (α-MSH), (which can stimulate human pulp fibroblasts in order to modulate pulpal inflamation) as a new active biomaterial for endodontic regeneration.

If the idea of nanorobots becomes realized, they would have a significant application in orthodontics. Manipulation with periodontal tissue would allow teeth movement and positioning [18].

Natural tooth appearance and durability, new forms of local anesthesia, treatment of dentine hypersensitivity, regeneration of tooth structure, improving preventive and regenerative procedures are also some areas for potential use of these nano-systems [2, 17, 18].

NANOTECHNOLOGY AS A RISK FOR HUMAN HEALTH AND ENVIRONMENT

The amount of free nanoparticles in nature depends on various factors: their physico-chemical properties, quantity and time of exposure. Nanomaterials released in the enviroment can be further modified by: temperature, pH, different biological conditions and presence of other pollutants. In this interaction nanomaterials can alter atmosphere, soil and water. These transformations and interactions can adversely affect the current state of the environment and be harmful to human health and balance of the ecosystems [31, 32, 33].

Nanoparticles have unique physicochemical properties that can be different in comparison with the same material in macroscale size. The main characteristic of these particles is greater difference between the surface area and unit weight, and higher surface reactivity [3, 4, 15]. It might lead to increased absorption through the lungs, skin, digestive tract and it might cause side effect to the lungs and other organs [2, 17]. Nanoparticles are so small that they can interact with DNA, RNA and other intracelular components. The question is what kind of immune response could be activated by these small particles, and what will be the metabolism, absorption and elimination path of these products?

There is a need for systemic solutions, monitoring and recording of potential hazard as well as finding timely responses in order to achieve safety for human health and environment.

CONCLUSION

It can be predicted that nanotechnology will have a great impact on dental research, dental prevention, diagnostics and treatment solutions. Major advances are expected in the sphere of preventive dentistry and mimicking processes that occur in nature (biomimetics). More accurate diagnostics will lead to detecting diseases in the earliest stages allowing timely applied treatment. Nanotechnology will create better treatment solutions themselves, and thus, overall features of oral health care will be improved. On the other hand, there are poorly understood risks for human health and environment that nanotechnology might cause. What will the application of nanotechnology and nanomaterials bring to the world, remains to be seen. However, nanotechnogy will be in focus of modern civilization reflection and action.

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Nanotehnologija u stomatologiji – sadašnjost i perspektive

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KRATAK SADRŽAJ
Nanotehnologija je multidisciplinarno polje naučnog istraživanja o različitim vrstama nanočestica, kao i o primeni nanomaterijala i nanouređaja u mnogim oblastima ljudskog interesovanja. Nanotehnologija nudi napredak u industriji, proizvodnim, informacionim i komunikacionim tehnologijama, elektronici, ekologiji i uštedi energije, ekonomiji itd. Gotovo da ne postoji oblast ljudske delatnosti u kojoj nanotehnologija i novi nanoproizvodi ne mogu imati uticaja. Kada se govori o nanoinovacijama, njihova primena u medicini i stomatologiji i pozitivni efekti upotrebe nanomaterijala i nanorobota neke su od glavnih tema. Međutim, nedovoljno poznavanje potencijalnih opasnosti po zdravlje ljudi i životnu sredinu dovodi do nesuglasica u naučnom i javnom mnjenju o tome šta su prednosti, a šta mane nanotehnološke evolucije, kao i kakva će biti budućnost kada nanotehnologija bude sastavni deo svakodnevice. Cilj ovog rada bio je da se predstavi značaj nanotehnologije u brojnim oblastima, a naročito u medicini i stomatologiji, i ukaže na moguće posledice njihovog uvođenja po zdravlje i životnu sredinu.
Ključne reči: nanotehnologija; nanomaterijali; stomatologija

UVOD

Još nije utvrđena jedinstvena definicija nanotehnologije, jer se postojeće definicije razlikuju u zavisnosti od svrhe upotrebe. Stoga se aktuelni pokušaji definisanja nanotehnologije mogu podeliti u tri osnovne grupe: naučne definicije, javne definicije i one koje omogućavaju donošenje određenih odluka [1].

Nanotehnologija je nauka, ali i proizvodni proces koji je uključen u dizajniranje, sintezu, karakterizaciju i primenu materijala i uređaja čija se najmanja jedinica mere u najmanje jednoj dimenziji nalazi na nanometarskoj skali (jedan milijarditi deo metra, 10^{-9} m) [2]. To znači da nešto što zovemo nanomaterijalom ili nanouređajem ima najmanju dimenziju od oko 100 nm ili manju, odnosno najviše 1×10^{-7} m. Poređenja radi, prečnik ljudske dlake je oko 50 µm, odnosno njen prečnik je pedeset hiljada puta veći od jednog nanometra [3]. Prosečni prečnik bakterije *Streptococcus mutans 10449* je 0,321±0,007 µm [4], dok je veličina jednog vodonikovog atoma u rasponu od 0,1 nm do 0,2 nm [5].

Nanotehnologija i nauka o nanomaterijalima imaju mogućnost obezbeđivanja prednosti u mnogim oblastima, kao što su: sinteza novih materijala s naprednim svojstvima, tehnologije proizvodnje, informacione tehnologije i elektronika, ekologija i ušteda energije, nanobiosistemi, primena u medicini, unapređenje transporta, ekonomije itd. Malo je verovatno da postoji bilo koji segment ljudskog života i delovanja na koji nanotehnologija neće imati uticaja; čak se procenjuje da će uticati na promene u psihologiji ljudi i njihovo razumevanje sveta u kojem žive (društveni fenomeni, filozofska gledišta i etička razmatranja) [6, 7, 8].

Prema definiciji Američkog nacionalnog instituta za zdravlje, nanomedicina jeste primena nanotehnologije u „veoma specifičnim medicinskim intervencijama na molekularnom nivou, odnosno u lečenju bolesti i reparaciji oštećenih tkiva, kao što su kosti, mišići i živci". Džonson (*Johnson*) i Megi (*McGee*) [9] naveli su možda bolju definiciju nanomedicine: „Nanomedicina podrazumeva medicinske intervencije u kojima se koriste materijali, mašine ili mehanizmi kreirani ili kontrolisani pomoću nanonauke i nanotehnologije radi posmatranja, unapređenja i održavanja zdravlja ljudi." U skladu s tim, moguće primene nanotehnologije u medicini su u ciljnoj isporuci lekova i genetskog materijala (virusni vektori, nevirusni vektori, kao što su nanočestice, lipozomi ili dendrimeri i tzv. *gene guns*), kao sredstvo u imidžing dijagnostici, molekularnoj dijagnostici, kardiološkoj terapiji, ortopediji itd. [2, 10-13].

Većina nanotehnologija koje se primenjuju u medicini može se takođe primeniti i u stomatologiji. Nanostomatologija poseduje potencijal višestrukog poboljšanja oralnog zdravlja omogućavanjem sofisticiranih preventivnih, dijagnostičkih i terapijskih mera primenom nanomaterijala, biotehnologija i nanorobota [14]. Stoga bi stanovništvo širom sveta moglo dobiti napredniju stomatološku zaštitu [2, 15].

Treba napomenuti da strukture veličine nanometra imaju posebna svojstva. Fizička i hemijska svojstva materijala izuzetno se menjaju kada se broj atoma koji čine materijal znatno smanji. Mali broj uslovljava drugačiji raspored i međurastojanje za površinske atome, a te osobine dominiraju fizičkim i hemijskim svojstvima objekta [5, 16].

NAGOVEŠTAJI NOVIH SAZNANJA

Na godišnjem sastanku Američkog društva fizičara davne 1959. godine fizičar i nobelovac Ričard F. Fajnman (*Richard P. Feynman*) izazvao je veliku pažnju naučne javnosti svojom revolucionarnom izjavom da „postoji dovoljno prostora na dnu". On je tada govorio o mogućnostima da se u budućnosti naprave materijali i uređaji na atomskom ili molekularnom nivou, te je uticao na to da se u ljudskoj svesti začne inovativan način razmišljanja. Predložio je da postojeće mašine prave manje alate kojima bi se pravile još manje mašine i alati, i tako sve do molekularnog nivoa. Ukazao je na to da bi se takve nanomašine, nanoroboti i nanouređaji mogli, naposletku, koristiti za razvijanje širokog spektra atomski preciznih mikroskopskih instrumenata i alata za proizvodnju. Svoje istorijsko predavanje Fajnman je zaključio rekavši: „To je razvojni put koji se ne može izbeći" [17, 18].

DANAS I SUTRA U STOMATOLOGIJI

Nanotehnologija nudi širok spektar inovacija i poboljšanja u prevenciji, dijagnostici i terapiji oboljenja zubnih struktura i potpornih tkiva. U oblasti restaurativne stomatologije, neprestanom razvoju doprinose i unapređene odlike kompozitnih materijala za zubne ispune. Sam način proizvodnje čestica punilaca za kompozitne materijale morao je biti promenjen s nanotehnološkog aspekta, kako bi se proizvele čestice manje od 100 nm. Tradicionalni postupak za proizvodnju malih čestica odlikuje mlevenje većih komada stakla, kvarca ili keramike – pristup „odozgo nadole" (engl. *top-down approach*). Za proizvodnju čestica manjih od 100 nm, navedena metoda je zamenjena direktnom molekularnom sintezom i povezivanjem (engl. *direct molecular assembly*) ili pristupom „odozdo nagore" sintezi nanočestica (engl. *bottom-up approach*), koji se ostvaruje hemijskim procesima. U poređenju s kompozitnim materijalima punjenim mikročesticama, nanopunjeni sistemi pokazuju bolje fizičke osobine, uključujući čvrstoću na pritisak, zateznu čvrstoću, žilavost, otpornost na savijanje i habanje itd. [5]. Osim toga, estetska svojstva nanomaterijala su mnogo bolja u odnosu na prethodne proizvode, prvenstveno zbog optičkih svojstava nanočestica, ali i poboljšanih potencijala za finalnu obradu, kao i dužeg očuvanja ispolirane površine [5]. Zasad postoje dve glavne vrste dentalnih kompozita punjenih nanopuniocima: tzv. nanohibridi i nanopunjeni. Nanohibridni kompozitni materijali sadrže punioce različitih veličina – npr. veće čestice stakla (u proseku veličine oko 2000 nm), mešane sa česticama veličine oko 10 nm, dok nanopunjeni imaju ujednačenije dimenzije čestica – npr. čestice veličine oko 75 nm mešane sa česticama veličine 5-25 nm. Nanopunjene kompozitne materijale odlikuje kombinacija nanočestica i tzv. nanooblaka (engl. *nanoclusters*), a komercijalni proizvod predstavlja *Filtek Supreme* (*3M ESPE*). Ovi materijali pokazuju poboljšana mehanička i fizička svojstva u poređenju s konvencionalnim kompozitnim materijalima za zubne ispune [19].

U budućnosti bi se nanotehnologija i biomimetički pristup (biomimetika – imitiranje prirodnih struktura i svojstava bioloških materijala) mogli koristiti za reparaciju i obnavljanje oštećene gleđi [20]. Čen (*Chen*) i saradnici [21] su sintetisali hidroksiapatitne nanoštapiće, koji imaju strukturu nalik na gleđne prizme (engl. *enamel-prism-like hydroxyapatite nanorods*). Ovi hidroksiapatitni nanoštapići imaju osobinu samopovezivanja i uklapanja (engl. *self-assembly*) i mogu postati nanorestauracije koje oponašaju procese koji se javljaju u prirodi, te bi se, kao takve, mogle koristiti u obnovi strukture zuba. Slične nanostrukture koje bi se takođe mogle koristiti u svrhu obnove zubne supstance jesu nanosfere – peptidi nastali genetskim inženjeringom koji se vezuju za površine od neorganskih materijala (engl. *genetically engineered peptides for inorganics – GEPIs*), te materijali na bazi amelogenina, restauracije koje otpuštaju fluor itd. [19, 22, 23].

Objavljeno je nekoliko studija koje su se bavile prevencijom karijesa koristeći prednosti nanotehnologije [20, 24-27]. U ovim istraživanjima sintetisani su i ispitani materijali sa nanočesticama, gde su karakterisani nanokristali dvofaznog kalcijum-fluorida, odnosno fluorisanog hidroksiapatita (engl. *biphasic calcium fluoride/fluorinated-hydroxyapatite – CF/FHAp nanocrystals*). Navedeni materijali su u uslovima *in vitro* ispitani kao potencijalni stomatološki ispuni s mogućnošću prevencije karijesa pomoću otpuštanja jona fluora [24]. Takođe, studija *in vitro* koju su realizovali Min (*Min*) i saradnici [25] pokazala je moguću primenu osvežavajućih pića s hidroksiapatitnim nanočesticama za sportiste, koja bi sprečavala stvaranje erozija na zubima. Kim (*Kim*) i saradnici [26] su u laboratorijskim uslovima ispitali dejstvo nanokarbonatnog apatita (engl. *nanocarbonate apatite – n-CAP*) u prevenciji ponovnog prebojavanja zuba nakon izbeljivanja. Ustanovili su da desetoprocentni n-CAP može značajno dugo održavati postignutu boju nakon estetskog tretmana izbeljivanja zuba, te omogućiti i adekvatan oporavak zubne gleđi.

Na osnovu dosadašnjih saznanja izvesno je da u nanotehnološkim otkrićima leži veliki potencijal u prevenciji karijesa u budućnosti. Čope (*Tschoppe*) i saradnici [27] zapazili su da zubne paste i preparati za prevenciju karijesa koji sadrže nanohidroksiapatit (engl. *nano-hydroxyapatite – n-HAp*) mogu poboljšati proces remineralizacije gleđi i dentina. U istraživanju *in vitro* poredili su dejstvo zubnih pasta s česticama n-HAp ili cink-karbonat-nanohidroksiapatita ($ZnCO_3$/n-Hap) s konvencionalnim fluoridnim pastama na remineralizaciju goveđe gleđi i dentina. Ustanovili su slične ili bolje efekte remineralizacije prilikom korišćenja zubnih pasti s nanočesticama [27].

U oblasti stomatološke implantologije, koja se stalno unapređuje, moguća su dalja poboljšanja primenom endoosealnih implantata izmenjenih tehnikama modifikacije površine u okviru nanoskale. Tako izmenjene osobine nanopovršina utiču na adheziju, proliferaciju i diferencijaciju ćelija. Proces oseointegracije može biti bolji i brži primenom površinske modifikacije zubnih implantata nanotehnologijom. Već postoji nekoliko komercijalnih implantatnih sistema s nanomodifikovanom površinom dostupnih za kliničku primenu [28]. Dugoročno praćenje u kliničkim uslovima ukazaće na prednosti i mane nanomodifikovanih površina zubnih implantata.

U najpopularnije istraživačke oblasti u stomatologiji ubrajaju se vođena tkivna i vođena periodontalna regeneracija, gde su već ostvareni značajni rezultati primenom nanotehnoloških modifikacija [29]. Istraživači pokušavaju da implementiraju nove materijale sa dodatkom nanočestica kao potke za prorastanje tkiva, radi poboljšanja sposobnosti obnavljanja tkiva. Srinivasan (*Srinivasan*) i saradnici [29] utvrdili su da eksperimentalne alginatne, odnosno nanobioaktivne stakleno-keramičke kompozitne potke mogu biti korisne u periodontalnoj regeneraciji. Ovakve strukture omogućavaju dobru adsorpciju proteina i adheziju i proliferaciju ćelija.

Mada savremeni protokoli lečenja od oboljenja zubne pulpe i apeksnih parodontita obezbeđuju visoku stopu uspeha, novi pristup u endodontskoj terapiji, koji bi ujedno predstavljao i idealnu terapiju, jeste indukovanje zamene obolelog ili nekrotičnog pulpnog tkiva zdravim. S tim ciljem Fjoreti (*Fioretti*) i saradnici [30] su obavili istraživanje kojim su ispitivali antizapaljenjske efekte koje imaju biološki aktivni višeslojni nanostrukturirani filmovi na fibroblaste. Prvi put su predstavili filmove koji sadrže melanokortne peptide (*α-MSH*), a koji mogu da stimulišu fibroblaste ljudske pulpe na modifikaciju zapaljenjskog procesa, kao nove aktivne biomaterijale za regeneraciju endodoncijuma.

Ako se ideja o nanorobotima ostvari, oni bi našli značajnu primenu u sferi ortodoncije. Manipulacijom periodontalnim tkivima omogućilo bi se pomeranje i pozicioniranje zuba u željene položaje [18].

Održavanje izgleda prirodnih zuba i njihova trajnost, novi vidovi lokalne anestezije, lečenje preosetljivosti zuba, obnavljanje njihove strukture, unapređenje mera prevencije i regenerativnih postupaka takođe su neke od oblasti u kojima je moguća primena navedenih nanosistema [2, 17, 18].

RIZIČNOST NANOTEHNOLOGIJA PO ZDRAVLJE LJUDI I ŽIVOTNU SREDINU

Količina slobodnih nanočestica u prirodi zavisiće od različitih faktora: njihovih fizičko-hemijskih svojstava, količine i vremena izloženosti. Nanomaterijali se u kontaktu sa životnom sredinom mogu dalje modifikovati pod uticajem temperature, pH, različitih bioloških uslova i postojanja drugih zagađivača. U takvoj interakciji nanomaterijali mogu izmeniti atmosferu, zemljište i vodene površine. Ovakve interakcije i transformacije imaju potencijal negativnog delovanja na postojeće stanje životne sredine, te mogu ugroziti zdravlje ljudi i ekosisteme [31, 32, 33].

Nanočestice nekog materijala imaju jedinstvena fizičko-hemijska svojstva, koja mogu biti različita u poređenju s istim materijalom u komadu, u makro veličini. Osnovna odlika ovih čestica jeste veća razlika između površine i mase po jedinici, kao i povišena površinska reaktivnost [3, 4, 15]. Takve osobine mogu dovesti do povećane apsorpcije nanočestica kroz pluća, kožu i digestivni trakt, te mogu izazvati sporedne efekte na plućima i ostalim organima [2, 17]. Nanočestice su tako male da mogu da reaguju sa DNK, RNK i unutarćelijskim komponentama. Stoga se postavlja pitanje kakav će biti imunološki odgovor na ovako male čestice i kakvi će biti metabolizam, apsorpcija i eliminacija ovih proizvoda?

Neophodno je istaći da postoji potreba za sistemskim rešenjima, posmatranjem i evidentiranjem potencijalnih opasnosti, kao i za blagovremenim iznalaženjem odgovora radi postizanja odgovarajućeg nivoa bezbednosti po zdravlje ljudi i životnu sredinu.

ZAKLJUČAK

Predviđa se da će nanotehnologija imati veliki uticaj na istraživanja u oblasti stomatologije i omogućiti unapređenje preventivnih, dijagnostičkih i terapijskih postupaka. Značajan napredak očekuje se u oblasti preventivne stomatologije i u nanotehnologiji koja oponaša biološke procese u prirodi (biomimetika). Preciznije dijagnostičke mogućnosti omogućiće otkrivanja bolesti u najranijoj fazi i pravovremeno otpočinjanje terapije. Nanotehnologija će, sama po sebi, kreirati i bolje terapijske mogućnosti, čime će celokupna zdravstvena zaštita biti podignuta na viši nivo. S druge strane, razumevanje i poznavanje rizika koje nanotehnologija predstavlja po zdravlje ljudi i životnu sredinu i dalje je nedovoljno. Šta će primena nanosistema doneti svetu ostaje da se vidi. Ono što je sigurno jeste da će nanotehnologija biti u žiži razmišljanja i delanja savremene civilizacije.

NAPOMENA

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