Primljen/ Recived on: 12.10.2015.
Revidiran/ Revised on:30.10. 2015.
Prihvaćen/ Accepted on:10.11..2015.

INFORMATIVNI RAD
INFORMATIVE ARTICLE
doi:10.5937/asn1572538G

NANOTEHNOLOGIJA U STOMATOLOGIJI: SADAŠNJA I BUDUĆA (OČEKIVANA) PRIMENA

NANOTECHNOLOGY IN DENTISTRY: CURRENT STATE AND FUTURE PERSPECTIVES

Nikola Gligorijević [1], Milena Kostić [2]

[1] STUDENT AKADEMSKIH DOKTORSKIH STUDIJA, MEDICINSKI FAKULTET, UNIVERZITET U NIŠU, SRBIJA
[2] UNIVERZITET U NIŠU, MEDICINSKI FAKULTET, KLINIKA ZA STOMATOLOGIJU, NIŠ, SRBIJA

[1] POSTGRADUATE STUDENT, FACULTY OF MEDICINE, UNIVERSITY OF NIŠ, SERBIA
[2]UNIVERSITY OF NIS, FACULTY OF MEDICINE,CLINIC OF DENTISTRY, NIŠ, SERBIA

Sažetak

Nanotehnologija je nauka koja se bavi istraživanjem i razvojem uređaja i materijala na molekularnom, odnosno, atomskom nivou, koja će u bliskoj budućnosti uticati na gotovo svaki aspekt ljudskog života. Danas možemo reći da je nanotehnologija sve prisutnija u polju medicinske dijagnostike i lečenja, uključujući i stomatologiju. Istraživači iz oblasti stomatoloških nauka uveliko istražuju potencijalne koristi nanotehnologije inkorporirane u postojeće terapeutske modalitete. Glavno polje njene primene u stomatologiji predstavljaju novi dijagnostički sistemi, lokalni agensi za oslobađanje leka, restorativni materijali, regenerativni materijali, materijali za koštane i tkivne graftove kao i poboljšanje strukture površine endostalnih implanata. Ovaj revijski rad pruža uvid u trenutni razvoj nanotehnologije u stomatologiji i razmatra njenu potencijalnu buduću primenu.

Ključne reči: *nanotehnologija, stomatologija, dijagnostika, materijali, dentalni implanti*

Abstract

Nanotechnology is a science that deals with the research and development of materials and devices at the atomic or molecular level. In the near future, almost every aspect of human life will be influenced by nanotechnologies. With the advancement in the technology, it is also getting incorporated in various medical diagnostic and treatment fields, including dentistry (nanodentistry). Researchers in the field of dentistry have explored the potential of nanoparticles in the existing therapeutic modalities with moderate success. The key implementations in the field of dentistry includes new diagnostic systems, local drug delivery agents, restorative materials, regenerative materials, bone and tissue graft materials and implant surface modifications. This review provides detailed insights into the current nanotehnology development in the field of dentistry, and discusses potential future uses of nanotechnology.

Key words: *nanotechnology, dentistry, diagnosis, materials, dental implants*

Corresponding author:
Nikola Gligorijević, DMD
Department of Prosthetic Dentistry,
Clinic of Dentistry , Blvd. dr Z. Djindjića 52,
18000 Niš, Serbia
Tel. +381653366646;
E-mail: dr.gligorijevicnikola@gmail.com

Uvod

Termin *nano* je izveden iz grčke reči *nan (n) os*, što znači *patuljak*. Nanotehnologija je nauka koja se bavi manipulacijom materije na atomskom nivou [1]. Nanotehnologijom se smatraju nauka i inženjering koji su uključeni u dizajn, sintezu, karakterizaciju i primenu materijala i uređaja čija je najmanja jedinica merenja u najmanje jednoj dimenziji na nanometarskoj skali (jedan milijarditi deo metra, 10^{-9} m)[2].

Dr Ričard Fajnman je prvi uveo koncept nanotehnologije 1959. godine. On je u svom predavanju pod nazivom "Nanotehnologija: Mali svet" diskutovao o ovoj temi[3].

Termin nanotehnologija uveo je Norio Taniguči 1974. godine[4]. Kasnije, godine 1986. K. Erik Drekler je doprineo njenom razvoju uvođenjem koncepta molekularne nanotehnologije u svoju publikaciju "Motori stvaranja: Dolazak doba nanotehnologije" [5], što je dovelo do razvoja lakih, ali jačih materijala, sa visokim hemijskim i mehaničkim svojstvima[3]. Od tada je nanotehnologija u velikoj meri napredovala u različitim oblastima nauke, pa i u stomatologiji.

Nanotehnologija podrazumeva razvoj materijala, uređaja i sistema koji ispoljavaju različite osobine u odnosu na te iste materijale, uređaje i sisteme većih dimenzija. U nanodimenzionom opsegu (1-100 nm) donju granicu na skali predstavlja veličina atoma vodonika (0,25 nm), dok je gornja granica definisana pojavom osobina tipičnih za materijale većih razmera.

U nanotehnologiji se koriste dva glavna pristupa u izradi materijala i uređaja. Prvi je *odozdo prema gore* pristup, gde se izgradnja materijala i uređaja vrši od molekularnih komponenti koje se međusobno povezuju na osnovu hemijskih zakona zasnovanih na principima molekularne diferencijacije. Drugi je *odozgo prema dole* pristup, gde izgradnja materijala i uređaja nastaje od komponenti velikih dimenzija bez ikakve kontrole na njihovom atomskom nivou[6].

Postoji veliki broj nanočestica koje su u upotrebi. U njih se ubrajaju: nanopore, nanocevi, kvantne tačke, dendrimeri, lipozomi, nanoštapići, fulereni, nanosfere, nanoniti, nanokaiševi, nanoprstenovi i nanokapsule[7].

Introduction

The term “Nano” is derived from the Greek word *nan(n)os* which means “dwarf”. Nanotechnology is a science that deals with manipulation of matter at the atomic level [1]. 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) are considered *nanotechnology*[2].

Dr. Richard Feynman was the first to introduce the concept of nanotechnology in 1959 discussing his viewpoint in this regard in his lecture entitled “*Nanotechnology*: It’s a small world” [3].

The term *nanotechnology* was introduced by Norio Taniguchi in 1974 [4]. Later in 1986, K. Eric Drexler contributed to its development by introducing the concept of molecular nanotechnology in his 1986 publication – “Engines of creation: the coming era of nanotechnology”[5].This concept led to the development of lighter but stronger materials with higher chemical and mechanical properties[3]. Since then, nanotechnology has greatly advanced in different fields of science, and dentistry has been no exception.

Nanotechnology involves the development of materials, devices, and systems exhibiting properties that are different from those found on a larger scale. In the nanodimension range of 1-100 nm, the lower limit is marked by the size of a hydrogen atom (0,25 nm) and the upper limit commences from a size where phenomena different from larger structures start appearing.

In nanotechnology, the two main approaches are used. Firstly, the ‘bottom-up’ approach, where construction of materials and devices is done from molecular components that self-assemble chemically based on the principles of molecular differentiation. Secondly, ‘top down’ approach, where construction of materials and devices is done from large units without any control at the atomic level [6].

There is a number of nanoparticles used including nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes, nanospheres, nanowires, nanobelts, nanorings and nanocapsules[7].

Stomatološka dijagnostika

Kvantne tačke

Smatra se da je biofilm najčešći uzročnik većine dentalnih i periodontalnih problema. Specifični patogeni mikroorganizmi su povezani sa razvojem zubnog karijesa i periodontalnih infekcija izazvanih plakom.

Tehnologija u kojoj se za imunofluorescenciju koriste kvantne tačke nanopraha omogućava označavanje određenih bakterija, njihovu identifikaciju i uklanjanje. Ova tehnika omogućava odličnu jednoćelijsku rezoluciju označavanja parodontalnih patogena kako u *in vivo* tako i u *in vitro* probama [8].

Ofnaset

Pored karijesa i periodontalnih poremećaja uzrokovanih plakom, usna šupljina je često podložna autoimunim poremećajima i karcinomatoznim promenama. Jedan od osnovnih ciljeva nanotehnologije u stomatologiji jeste stvaranje i implementacija isplativih visoko senzitivnih salivatornih dijagnostičkih sistema.

Senzorni nano test oralnih fluida (OFNASET, Vong laboratorija, Univerzitet u Kaliforniji, Los Anđeles) je veoma osetljiv, specifičan, prenosiv i automatizovan nanoelektromehanički sistem, koji omogućava preciznu identifikaciju pljuvačnih proteomičnih biomarkera i nukleinskih kiselina specifičnih za oralne karcinome, i to četiri mRNK biomarkera (SAT, ODZ, IL-8 i IL-1β) i dva proteomična biomarkera (tioredoksin i IL-8) [9].

Preventivna stomatologija

Paste za zube

Paste za zube i tečnosti za ispiranje usta su najčešće korišćeni preparati u sklopu preventivnih mera za kontrolu plaka.

Poznato je da je proces remineralizacije gleđi uslovljen lokalnom koncentracijom minerala apatita. Nanočestice kalcijum-karbonata ili hidroksiapatita su slične morfologiji i kristalnoj strukturi gleđi [10].

Paste za zubnu preosetljivost koje sadrže nano-hidroksiapatit (n-HAP) ili nano-karbonat apatit (n-CAP) čestice trenutno su u fazi testiranja. Neorganskoj komponenti zuba sličan je n-CAP i poznato je da ima visoku rastvorljivost i neutralniji pH. U poređenju sa konvencionalnim agensima n-CAP dokazano je efikasnija kratkotrajna desenzibilišuća pasta za zube [11].

Diagnostic dentistry

Quantum dot

Biofilms are considered the root cause of most dental and periodontal diseases. Specific pathogenic microorganisms have been associated with the development of dental caries and plaque-induced periodontal infections.

Technology employing nanosized *quantum dots* based on immunofluorescence enables the labelling of specific bacteria, which eases their identification and removal. This technique provides excellent single cell resolution for both *in vivo* and *in vitro* labeling of periodontal pathogens [8].

Ofnaset

Apart from dental caries and plaque induced periodontal disorders, the oral cavity is often afflicted by autoimmune disorders and carcinomatous changes. One of the goals of nanotechnology in dentistry is the creation and implementation of cost-effective technological advancements in highly sensitive salivatory diagnostics systems.

The Oral Fluid Nano Sensor Test (OFNASET, The Wong Lab, University of California, Los Angeles) is a highly sensitive, specific, portable, and automated nanoelectro-mechanical system, which enables point-of-care detection of salivary proteomic biomarkers and nucleic acids specific for oral cancer, including 4 mRNA biomarkers (SAT, ODZ, IL-8, and IL-1β) and 2 proteomic biomarkers (thioredoxin and IL-8) [9].

Preventive dentistry

Dentifrices

Dentifrices and mouthwashes are the mostly widely used products in preventive plaque control measures.

It is known that the process of enamel remineralization is governed by the local concentration of apatite minerals. Nanosized calcium carbonate particles or hydroxyapatite crystals are similar to the morphology and crystal structure of enamel [10].

Dentifrices for dental hypersensitivity that incorporate nanohydroxyapatite (n-HAP) or nanocarbonate apatite (n-CAP) particles are currently being tested. n-CAP is similar to the inorganic component of teeth and is known to have a high solubility and a

Tečnosti za ispiranje usta

Tečnosti za ispiranje usta koje sadrže nanočestice triklosana i nanočestice srebra efikasne su u kontroli potencijala za nastanak zubnog plaka. Koloidne suspenzije triklosan nanočestica pokazale su visok stepen supstitutivnosti zbog prisustva bioadhezivnih polimera u sistemu [12]. Na ovaj način se stvara sistem sa kontrolisanim oslobađanjem koji poseduje bioadhezivna svojstva zbog prisustva površinski aktivnog surfaktanta na površini mikročestica. Ovaj sistem je moguće ugraditi u gelove, paste za zube i tečnosti za ispiranje usta sa ciljem lečenja i prevencije periodontalnih bolesti [13].

Restorativna stomatologija

Nanofileri

Ugrađivanje nanofiler čestica u kompozitne smole dovelo je do nove klase materijala sa poboljšanim svojstvima – mikro i makropunjenih kompozita. Nanofileri smanjuju stepen polimerizacionog skupljanja i toplotne ekspanzije, povećavaju sposobnost poliranja i tvrdoću materijala čineći ga otpornijm na habanje[14,15]. Veličina ovih čestica se kreće od 0,005-0,01 μm. U ovoj veličini, smole i čestice filera prikazuju optička svojstva frakcije talasne dužine svetlosti. Shodno tome, ove čestice prestaju da reflektuju svetlost, što dovodi do ekspresije boja bližih fiziološkim bojama zubnih struktura. Proizvodnju nanofilera moguće je izvesti uz primenu pristupa *odozdo prema gore*. Sintetisana su dva različita tipa nanofilera: nanomeri (5-75 nm) i nanoklasteri (2-20 nm). Ugrađivanje nanomera (5-75 nm) i nanoklastera (2-20 nm) u postojeće matrikse komercijalno dostupnih smola pokazalo je poboljšanje optičkih svojstava i poboljšalo poliranje mikrofiler kompozita, kao i poboljšanje snage hibridnih kompozita[14].

Dodavanjem nanofilera postignuto je poboljšanje i smolom modifikovanim glas jonomer cementa (RMGIC). Karakteristike na koje se odnosi ovo poboljšanje jesu veća sposobnost poliranja ovih cemenata i njihova bolja estetska svojstva[16].

Uključivanjem nanofilerima obogaćene smole u samovezujuće sisteme glas jonomer cementa (GIC) za posteriorne ispune takođe se postigla visoka hidrofilnost i zaštita od habanja abrazijom[17]. Niska viskoznost premaza obezbeđuje optimalnu

more neutral pH. When compared to conventional agents, n-CAP has proven to be an efficacious short-term desensitizing dentifrice [11].

Mouthwashes

Mouthwashes containing nanoparticles loaded with *triclosan* and *silver nanoparticles* have demonstrated plaque control potential. The colloidal suspensions of triclosan nanoparticles have shown high substantitvity due to the use of bioadhesive polymers in the system[12]. This creates a controlled-release system with bioadhesive properties due to the presence of a positively charged surfactant on the microparticle surface. This system can be incorporated into gels, toothpastes, and mouthwashes for the treatment and prevention of periodontal diseases [13].

Restorative dentistry

Nanofillers

The incorporation of nanofiller particles in composite resins has given rise to a new class of materials with improved properties over micro - and macrofilled composites.Nanofillers reduce the polymerization shrinkage and thermal expansion, and enhance the polishing ability, hardness, and wear resistance of composites The size of these particles ranges from 0.005-0.01 μm. At this size, the optical properties of the resin and the filler particles become a fraction of the wavelength of light. Consequently, these particles cease to reflect back light, resulting in a more physiologic color expression by the material. The bottoms-up approach is required for the production of nanofiller particles. Two different types of nanofillers, nanomers (5-75 nm) and nanoclusters (2-20 nm) have been synthesized. The incorporation of nanomers (5-75 nm) and nanoclusters (2-20 nm) into the existing resin matrix system has been shown to improve the optical and polishing properties of microfill composites and the strength of hybrid composites [14].

An improvement has also been made to resin-modified glass ionomer cement (RMGIC) with the addition of nanosized fillers. This has been reported to improve the polishability and esthetic properties of the RMGIC [16].

The inclusion of nanofilled resins in posterior restorative GIC self-adhesive ispunjenost i glazuru površine GIC, čime se obezbeđuje vreme da „ispun sazri" i poveća svoje estetske karakteristike[17]. Imajući to u vidu, može se reći da se poboljšanja u tehnologiji filera mogu koristiti za razvoj novih resturativnih materijala na bazi smola sa poboljšanim mehaničkim osobinama [18, 19].

Regenerativna stomatologija

Koštani graftovi

Razvoj veštačkih materijala za supstituciju koštanog tkiva bio je uslovljen željom za izbegavanjem dodatne hirurške procedure kojom se obezbeđuje, neretko, nedovoljna količina koštanog grafta. Potreba veće biokompatibilnosti dovela je do razvoja trenutno dostupnih aloplastičnih koštanih graftova.

Najpopularniji do sada su nano-hidroksiapatitni (n-HAP) koštani graftovi koji su dostupni u obliku kristalin, citozan-povezane i titanijum-ojačane forme [20-22].

Osim HAP, od 1892. godine upotrebljava se i kalcijum sulfat ($CaSO_4$) kao oblik biorazgradivog i osteokonduktivnog koštanog suspstituenta [23,24].

Razvijen je nanoprah kristala, konvencionalno dostupnih $CaSO_4$ koštanih graftova, sa veličinama čestica u rasponu 200-900 nm. Veličina čestica konvencionalno dostupnih $CaSO_4$ koštanih graftova kreće se od 30-40 µm. Ove nanočestice se dalje kondenzuju u granule od 425-1000 µm. Ovo umanjenje čestica dovodi do materijala za graftove koji su otporniji na degradaciju i koji duže traju (12-14 nedelja) u odnosu na konvencionalne $CaSO_4$ koštane graftove (4-6 nedelja). Stopa degradacije odgovara stopi rasta kostiju unutar koštanih defekata, čime se dobija bolji oporavak oštećene koštane strukture [25].

Nedavno je razvijen antibakterijski nanokeramički kompozitni materijal impregnacijom nanočesticama nanokalcijum-fosfata, ugljeničnim nanotubulima i cink-oksidom (ZnO) u alginatni polimerni matriks [26]. Ovaj materijal poboljšava stvaranje HAP u koštanim defektima [27].

Upotreba nanočestičnih koštanih graftova pokazuje se kao perspektivna kod post-ekstrakcionog očuvanja grebena, obnavljanja intrakoštanih nedostataka, perforacija kanala korena zuba, sinus-liftova, dehiscencije implantata i korekcija fenestraciije.

coatings has also demonstrated high hydrophilicity and protection against abrasive wear[17]. The low viscosity of the coating provides an optimal seal and glaze to the GIC surface, which gives time for the restoration to mature and increases its esthetic properties [17]. Thus, it could be stated that these improvements in filler technology can be used to develop new resin-based dental restoratives with enhanced mechanical properties [18,19].

Regenerative dentistry

Bone grafting

Artificial bone substitutes were concomitantly developed in order to avoid the drawbacks of second site surgery and inconsistent graft quantity. The constant search for better biocompatibility led to the current development of different alloplastic bone grafts that are currently being used and tested.

The most popular ones to date are nano hydroxyapatite (n-HAP) bone grafts, which are available in crystalline, chitosan-associated and titanium-reinforced forms [20-22].

Apart from HAP, the use of calcium sulphate ($CaSO_4$) as a biodegradable and osteoconductive bone substitute has been utilized since 1892 [23, 24].

Nanosized crystals of conventional $CaSO_4$ bone grafts have now developed, with particulate sizes ranging from 200-900 nm, while the conventional $CaSO_4$ bone graft particle size ranges from 30-40 µm. These nanoparticles are further condensed into pellets of 425-1000 µm. This nanotization of particles results in a graft material which is more resistant to degradation and lasts longer (12-14 weeks) than conventional $CaSO_4$ (4-6 weeks). This rate of degradation matches the rate of bone growth in the intrabony defects, resulting in better treatment outcomes [25].

Recently, an antibacterial nanoceramic composite material has been developed by impregnating nanocalcium phosphate, walled carbon nanotubes, and zinc oxide (ZnO) nanoparticles into an alginate polymer matrix[26]. This material enhances HAP formation in bone defects [27].

The use of nanoparticulate bone grafts show promise in postextraction ridge preservation, intrabony defects regeneration, root perforations, sinus-lift procedures, implant dehiscence, and fenestration corrections.

Vođena tkivna i periodontalna regeneracija

U jednoj od najpopularnijih oblasti stomatologije, vođenoj tkivnoj i periodontalnoj regeneraciji, dobijeni su obećavajući rezultati implementacijom nanotehnologije u ove postupke[28]. Novi materijali sa dodatkom nanočestica treba da posluže kao matrice za tkivno urastanje kako bi se poboljšala regenerativna sposobnost tkiva. Srinivasan i saradnici su ustanovili da kombinacija eksperimentalnog alginata i nano-bioaktivnog stakleno-keramičkog kompozitnog skeleta može biti korisna kod periodontalne regeneracije [28]. Ovakva struktura obezbeđuje dobru adsorpciju proteina i ćelijsku adheziju i njihovu proliferaciju.

Membrane za vođenu tkivnu regeneraciju oplemenjene *nanougljeničnim hidroksiapatitom, kolagen i polimlečno-ko-glikolnom kiselinom* (nCHAC/PLGA) pokazuju poboljšanu fleksibilnost, manji stepen nekompatibilnosti i bolju osteokonduktivnost. Genetski aktiviran matriks predstavlja kolagenski skelet sa citosan plazmidnim nanočesticama kodiranim za PDGF (trombocitni faktor rasta).

Dentalna implantologija

Implementacijom nano površinskih modifikacija endosealnih implantata stvara se prostor za dalja poboljšanja u domenu dentalne implantologije. Tako izmenjene osobine nano površina utiču na ćelijsku adheziju, njihovu proliferaciju i diferencijaciju. Proces oseointegracije mogao bi biti bolji i brži kod korišćenja ovog tipa površinskih modifikacija. Već postoji nekoliko komercijalno dostupnih implantat-sistema koji su površinski nano-modifikovani [29].

Regeneracija pulpe

Upotreba nanotehnologije ima potencijala i u oblasti regeneracije pulpe. Razvoj tkiva, koje bi zamenilo bolesno ili oštećeno tkivo pulpe, predstavljao bi revolucionarno otkriće u odnosu na trenutnu doktrinu uklanjanja patološki izmenjenog tkiva pulpe. Poznato je da α-melanocit-stimulišući hormon (α-MSH) poseduje antiinflamatorna svojstva. Nedavna istraživanja su pokazala potencijal nanofilmova koji sadrže α-MSH kod revitalizacije oštećenog zuba[30]. Dalja istraživanja su neophodna kako bi se dodatno ispitala predložena terapijska dejstva ovakvog regenerativnog pristupa.

Guided tissue and periodontal regeneration

Some promising results using nanotechnology modification have already been obtained in one of the most popular areas in dentistry, guided tissue and periodontal regeneration[28]. New materials with addition of nanoparticles should serve as a scaffold for tissue ingrowths to improve the ability of tissue regeneration. Srinivasan et al.[28] 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.

Guided tissue regeneration membranes incorporated with *nanocarbonated hydroxyapatite / collagen / polylactic-co-glycolic acid* (nCHAC/PLGA) show improved flexibility, incompatibility, and osteoconductivity. The gene-activated matrix represents collagen scaffold with chitosan/plasmid nanoparticles encoding for PDGF (platelet-derived growth factor).

Dental implantology

The implementation of nanoscale surface modifications of endosseous implants creates room for further improvements in dental implantology. 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 [29].

Pulp regeneration

The use of nanotechnology has potential in the region of dental pulp regeneration. The development of tissues to replace diseased or damaged dental pulp can provide a revolutionary alternative to pulp removal. The *α-melanocyte-stimulating hormone* (α-MSH) is known to possess anti-inflammatory properties. Recently, it has been suggested that nanofilms containing α-MSH could help revitalize damaged teeth[30]. Further research is needed to evaluate these proposed therapeutic and regenerative approaches.

Regeneracija nerava

Nanočestice je moguće upotrebiti za rekonstrukciju oštećenih nerava uz upotrebu samopovezujućih nanovlakana koje se zovu amfifili. Povezani amfifili mogu dostići dužinu i do nekoliko mikrometara i mogu se koristiti u *in vivo* uslovima kako bi se premostio tkivni defekt koštane srži[31]. Upotreba ovih materijala ima veliki potencijal u domenu oralne hirurgije, recimo, kod potencijalne rekonstrukcije oštećenog inferiornog alveolarnog nerva nakon opsežne oralno hirurške procedure.

Zaključak

Nanotehnologija će imati veliku ulogu u istraživanjima u stomatologiji, u stomatološkoj prevenciji, u dijagnostičkim i terapijskim procedurama. Glavna poboljšanja se očekuju u oblasti preventivne i rekonstruktivne stomatologije upotrebom procesa biomimetike (imitiranja prirodnih dešavanja). Preciznija dijagnostika će dovesti do ranog otkrivanja bolesti i time omogućiti pravovremeno primenjivanje adekvatnog terapijskog tretmana. Razvoj nanotehnologije i njeno korišćenje u stomatologiji bi trebalo da dovede do boljeg opšteg stanja oralnog zdravlja. S druge strane, tek treba ispitati potencijalne rizike primene ove tehnologije kao i njen uticaj na zdravlje ljudi i životnu sredinu. Ostaje da se vidi šta će primena nanotehnologije i nanomaterijala doneti svetu.

Nerve regeneration

Nanoparticles can also be applied to reconstruct damaged nerves, with self-aggregating rod-like nanofibers called amphiphiles. Aggregated amphiphiles may reach up to several micrometers in length and can be utilized *in vivo* to bridge tissue defects in the spinal cord[31]. This application holds huge potential in the oral surgical arena, such as the possible reconstruction of a damaged inferior alveolar nerve after extensive oral surgical procedures.

Conclusion

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 reconstructive dentistry by mimicking processes that occur in nature (biomimetic). More accurate diagnostics will lead to early disease detection allowing timely applied treatment. The development of nanotechnology and its use in dentistry should overall lead to better oral health. On the other hand, the risks on human health and environment are yet to be seen. What the application of nanotechnology and nanomaterials will bring to the world remains to be seen.

LITERATURA /REFERENCES

1. Kaehler T. Nanotechnology: Basic concepts and definitions. Clin Chem 1994;40:1797-99.
2. Sahoo SK, Parveen S, Panda JJ. The present and future of nanotechnology in human health care. Nanomed Nanotechnol Biol Med 2007; 3:20-31.
3. Duke ES. Has dentistry moved into the nanotechnology era? Compend Contin Educ Dent 2003; 24: 380-382.
4. Taniguchi N. Proceedings of the International Conference on Precision Engineering (ICPE). Tokyo, Japan 1974:18-23.
5. Drexler KE. Engines Of Creation: The Coming Era Of Nanotechnology. New York: Anchor Press; 1986:99-129.
6. Rodgers P. Nanoelectronics: Single file. Nature Nanotechnology 2006.
7. Freitas RA. Nanomedicine basic capabilities, Georgetown, TX: Landes Bioscience 1999;345-47.
8. Chalmers NI, Palmer RJ, Thumm LD, Sullivan R, Wenyuan S, Kolenbrander PE. Use of quantum dot luminescent probes to achieve single-cell resolution of human oral bacteria in biofilms. Applied Env Microbiol 2007; 73(2):630-636.
9. Gau V, Wong D. Oral fluid nanosensor test (OFNASET) with advanced electrochemical-based molecular analysis platform. Ann N Y Acad Sci 2007;1098:401-410
10. Vandiver J, Dean D, Patel N, Bonfield W, Ortiz C. Nanoscale variation in surface charge of synthetic hydroxyapatite detected by chemically and spatially specific high resolution force spectroscopy. Biomaterials 2005;26:271-283.
11. Lee SY, Kwon HK, Kim BI. Effect of dentinal tubule occlusion by dentifrice containing nano-carbonate apatite. J Oral Rehabil 2008;35(11):847-853.
12. BioNanoPlus Drug Delivery Technologies. Antiseptic Mouthwash. Available at: http:// bionanoplus.com / antiseptic-mouth - wash.html. 2014
13. Pragati S, Ashok S, Kuldeep S. Recent advances in periodontal drug delivery systems. Int J Drug Deliv. 2009; 1:1-14.
14. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc 2003;134(10):1382-1390.
15. Dresch W, Volpato S, Gomes JC, Ribeiro NR, Reis A, Loguercio AD. Clinical evaluation of a nanofilled composite in posterior teeth: 12-month results. Oper Dent 2006;31(4):409-417.
16. Vaikuntam J. Resin-modified glass ionomer cements (RM GICs) implications for use in pediatric dentistry. J Dent Child 1997;64(2):131-134.
17. Tanaka K, Kato K, Noguchi T, Nakaseko H, Akahane S. Change in translucency of posterior restorative glassionomer cements. [IADR Abstract] 2014. Available at: https://iadr.confex.com/iadr/2007orleans/techprogramforcd/A89310.htm.
18. Furmann BR, Nicolella D, Wellinghof ST, et al. A radiopaque zirconia microfiller for translucent composite restoratives. [abstract] J Dent Res 2000;79:246.
19. Youngblood TA, Nicolella DP, Lankford J, et al. Wear and select mechanical properties of a zirconia nanofilled resin composite. J Dent Res 2000;79:365.
20. Singh VP, Nayak DG, Uppoor AS, Shah D. Clinical and radiographic evaluation of nano-crystalline hydroxyapatite bone graft (Sybograf) in combination with bioresorbable collagen membrane (Periocol) in periodontal intrabony defects. Dent Res J 2012;9(1):60-67.
21. Reves BT, Jennings JA, Bumgardner JD, Haggard WO. Preparation and functional assessment of composite chitosan-nano-hydroxyapatite scaffolds for bone regeneration. J Funct Biomater 2012;3:114-130.
22. Kailasanathan C, Selvakumar N, Naidu V. Structure and properties of titania reinforced nano-hydroxyapatite/gelatin bio-composites for bone graft materials. Ceram Int 2012;38(1):571-579.
23. Greenwald AS, Boden SD, Goldberg VM, et al. Bonegraft substitutes: facts, fictions, and applications. J Bone Joint Surg Am 2001;83-A(Suppl 2 Pt 2):98-103.
24. Kelly CM, Wilkins RM, Gitelis S, Hartjen C, Watson JT, Kim PT. The use of a surgical grade calcium sulfate as a bone graft substitute: results of a multicenter trial. Clin Orthop Relat Res 2001;382:42-50.
25. Kathuria R, Pandit N, Jain A, Bali D, Gupta S. Comparative evaluation of two forms of calcium sulfate hemihydrate for the treatment of infrabony defects. Indian J of Dent Sci 2012;4(2):30-36.
26. Beherei HH, El-Magharby A, Abdel-Aal MS. Preparation and characterization of novel antibacterial nanoceramic-composites for bone grafting. Der Pharma Chemica 2011;3(6):10-27.
27. Beherei HH, El-Magharby A, Abdel-Aal MS. Preparation and characterization of novel antibacterial nanoceramic-composites for bone grafting. Der Pharma Chemica. 2011;3(6):10-27.
28. Srinivasan S, Jayasree R, Chennazhi K, Nair S, Jayakumar R. Biocompatible alginate/nano bioactive glass ceramic composite scaffolds for periodontal tissue regeneration. Carbohyd Polym 2012; 87:274-83.
29. Mendonca G, Mendonca D, Aragao F, Cooper L. Advancing dental implant surface technology – from micron- to nanotopography. Biomater 2008; 29:3822-35.
30. Fioretti F, Palomares CM, Helms M, et al. Nanostructured assemblies for dental application. ACS Nano 2010;4(6):3277-3287.
31. Ellis-Behnke RG, Liang YX, You SW, et al. Nano neuro knitting: peptide nanofiber scaffold for brain repair and axon regeneration with functional return of vision. Proc Natl Acad Sci U S A 2006;103(13):5054-5059.