ejpmr, 2023, 10(5), 504-510

SJIF Impact Factor 6.222

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

Review Article

ISSN 2394-3211

EJPMR

ROLE OF NANOROBOTS IN DENTISTRY – A REVIEW

Dr. Suchetha Aghanashini[1], Dr. Tushar Udaykumar Nadagadalli*[2], Dr. Sapna Nadiger[3], Dr. Darshan Basavaraj Mundinamane[3], Dr. Apoorva Sokke Mallikarjunappa[3] and Dr. K. Vinodhini[4]

[1]MDS, Professor and Head, Department of Periodontics, D A P M R V Dental College, Bangalore.
[2]Postgraduate Department of Periodontics, D A P M R V Dental College, Bangalore.
[3]MDS, Reader, Department of Periodontics, D A P M R V Dental College Bangalore.
[4]MDS, Senior Lecturer, Department of Periodontics, D A P M R V Dental College Bangalore

***Corresponding Author: Dr. Tushar Udaykumar Nadagadalli**
Postgraduate Department of Periodontics, D A P M R V Dental College, Bangalore.

Article Received on 19/03/2023 **Article Revised on 08/04/2023** **Article Accepted on 28/04/2023**

ABSTRACT
Advanced technologies has always been a high demand in medical and the dental field in order to provide reliable and comfortable therapeutic option making treatment procedures less invasive, fast, effective and safe for the patients. one such emerging advanced technology is nanorobotics. Nanorobots remain a hypothetical concept as no artificial non biologic nanorobots have been created till date. But emergence of nanorobotics in heathcare sector will change the face of medical and dental sciences. This review focuses on nanorobots design , its mechanism and its possible applications in medical and dentistry field.

KEYWORDS: Nanorobots, Nanodentistry, *Nanoid*, Nanobiosensors.

INTRODUCTION

The field of medicine and dentistry has advanced eminently in recent years through the vision of the late Nobel Physicist Richard P Faymen's introduction of nanotechnology in the year 1959 which requires the creation and utilization of all the systems i.e., chemical, physical, and biological systems with structural features between atoms or molecules to submicron dimensions, and also the acclimation of resultant nanostructures into larger systems. According to the definition of the National Nanotechnology Initiative, nanotechnology is the direct manipulation of materials at the nanoscale.[1,2]

Nano is measured as one billionth of a meter or 10^{-9} of a meter. The prefix is derived from the Greek word "nano" meaning dwarf. This term defines a technology that enables almost complete control of the structure of matter at nanoscale dimensions.[3,4]

The medical world has introduced the use of robots for basic surgical procedures, and recently under the aegis of nanobiotechnology robotics has been developed into the next dimension as nanorobots or nanobots.[1]

Nanodentistry is the term used for the utilization of nanotechnology used in the field of dentistry. Robert A Frietas defines nanodentistry as "the science and technology that will make possible the maintenance of comprehensive oral health by employing the use of nanomaterials, biotechnology including tissue engineering and ultimately nanorobotics".

In the field of regenerative medicine and tissue engineering, scientists are recurrently applying the principles of cell transplantation, material science, and bioengineering to fabricate biological substitutes that will aid in the restoration and maintenance of normal function in diseased and injured tissue.[5]

The present article aims to review the current status of nanotechnology in the field of medicine and dentistry and also provide insight into the various possible applications in the future. Thus, also highlights the concerns associated with the use of this technology for improving and transforming them into solid bases for novel methods.[6]

Nanorobotics

Nanoid robotics, or nanorobotics or nanobotics, is an advanced and evolving discipline in the sector of nanotechnology for designing machines or robots at or close to the microscopic scale of nanometers (10^{-9}). According to the theory of nanorobotics "nanorobots being microscopic in size, will likely be necessary for numerous of them to unite and work and perform microscopic & macroscopic tasks". They can be synonymously known as *nanobot*, *nanoid*, *nanite*, *nanomachine*, and *nanomite*.[7,10]

Nanorobotics maneuvers nanoscale objects employing micro or macro devices, as well as the design and programming of robots with overall dimensions at the nanoscale (or with microscopic dimensions but nanoscopic components).[11]

Nanoscale machines known as "nanorobots" were once only found in science fiction.They are now predicted to be the next generation of nanodevices capable of improving medical diagnosis and drug delivery.[12]

Knowledge of their parts, construction, and mechanism of action plays a very important role in their usage in the field of medicine and dentistry.

Parts of Nanorobots

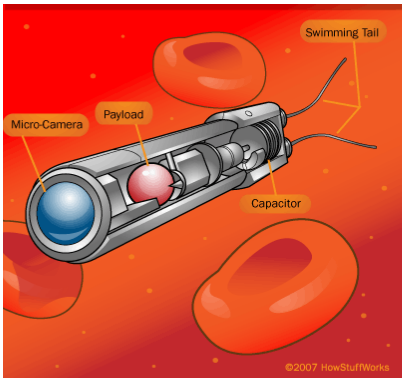

Figure: 1.

Constitutes a camera, payload, capacitor (energy storage unit), and swimming tail. The diameter ranges from 0.5 to 3 microns and will be constructed out of parts with dimensions of a range of 1 to 100 nm.[13]

1. **Payload:** This vacant portion stores a modest dose of medicines or medicine. The nanorobots might travel through the bloodstream to the location of illness or injury an administer the medicine.
2. **Micro camera:** The nanorobot could include a microscopic camera. The user can steer the nanorobot while manually travelling through the body.
3. **Electrodes:** By utilising the electrolytes in the blood, the electrode implanted on the nanorobot may be able to build a battery. These protruding electrodes could also destroy cancer cells by producing an electric current and heating them to death.
4. **Lasers** have the potential to burn hazardous materials such as artery plaque, blood clots, or cancer cells.
5. **Ultrasonic signal generators** are utilised when nanorobots target and eliminate kidney stones.
6. **Swimming tail:** Because nanorobots go against the flow of blood in the body, they will need a form of propulsion to enter the body.[14]

DESIGN OF NANOROBOTS

The design is derived from biological models of bacteria. The essential element used in the construction of nanorobots is carbon likely built in the form of a diamond (includes pure diamond and crystalline allotrope of carbon) or fullerene nanocomposites because diamond particles are chemically inert, have high thermal conductivity, and have strength. other light elements, such as sulfur, hydrogen, nitrogen, oxygen, fluorine, etc. will be used for special purposes in nanoscale gears and other components. Ultra-smooth surface of nanorobots will provide a streamlined path for them as these won't trigger the immune system. Based on its task, nanorobots will have other biochemical or molecular parts besides glucose or natural body sugars and oxygen as a source for propulsion. [16,17]

The dental nanorobot perhaps has an onboard nano-computer that will store and execute pre-programmed actions and will be able to collect and process signals and external stimuli. A multi-armed spider-like configuration seems the most ideal design among various designs of nanorobots that have been suggested as it may allow high-speed motility and multitasking capability.

The dental nanorobot can be designed to use energy from internal sources (radioactive particles, solar cells) or external sources (body heat, blood glucose). They can be programmed with two-way communication with the operating dentist via acoustic signals or electromagnetic waves. They can also work alongside other nanorobots with light signals, optical nanosensors, or chemical nanosensors.[18,19]

Challenges in Designing Nanorobots

The difficult tasks that come across while constructing nanorobots include

1. The requirement for the development of extremely fine instruments and handling procedures capable of assembling individual nanostructures with great precision into the operational device.
2. On the nanoscale, the distinctness of adhesion and friction is a less visible challenge. Reducing the existing design of a macroscopic device with moveable parts to a nanoscale is unfeasible because of the high surface energy of the nanostructures, indicating that all contacting points will stick together following the principle of energy minimization. This causes the pieces to break before they begin to move relative to each other because the adhesion and static friction between these parts readily exceeds the strength of the materials. This involves the creation of mobile structures with little interaction..[20]

Mechanism of Action

Freitas first described the mechanism of action of medical nanorobots in 1999. The charging of nanorobots can be done by metabolizing local glucose and oxygen for energy and externally providing acoustic energy.

Nanorobots' functions will be regulated by simple onboard computers that have the potential to carry out 1000 or fewer computations per second. Communication with the device can be accomplished through broadcast-type acoustic signaling. Positional accuracy is provided by installing a navigational device in the body for all passing robots that interrogate them, wanting to know their location, and in this way, it will help the physician to keep track of the various devices in the body. They will be able to distinguish between different cell surfaces by checking the surface antigen by using chemotactic sensors keyed to a specific antigen. Scavenger systems can be used for retrieval following completion of the task or permitting them to effuse themselves via the human excretory system.[21,22]

Manufacturing

Two approaches for manufacturing medical nanorobots are suggested according to researcher Adriano Cavalcanti from the Center for Automation of Nanobiotech (CAN) in Brazil.

1. Organic nanorobots (Also known as bionanorobots): Manufactured using proteins and polynucleotides.
2. Inorganic nanorobots: Manufactured using metals or diamonds. Metals have double benefit Ex: silver- serve as the base of a nanorobot and has an antibacterial effect. Diamond – has high strength and high performance.[23,25]

Applications

Nanorobotics has incredible applications in the field of medicine and dentistry and is thus expected to provide exceptional possibilities. Nanorobots have found their use in various areas of medicine. Henceforward, nanobots will play an important role in medicine, such as a "nanodoctor" inside the body including pharmaceutics, diagnostics, gene therapy, and dentistry.[12,26]

A. Medical applications

- Medical nanorobots perform a wide range of functions such as diagnostic, testing and monitoring both in tissues and as well as in the bloodstream. Also records and reports all vital signs with temperature, pressure, chemical composition, and immune system activity, from different parts of the body.[27]
- Nanorobots with chemical nanobiosensors –

i. Cancer treatment has special importance because it is the leading cause of death in the world. The nanobot will move independently around the body and detect a cancer cell. Therefore, when are inside or interacting with the cancer cells they will release the drug. In this way, the side effects of anti-cancer drugs on other parts of the body will be reduced. Nanorobots detect and destroy tumor cells in the early stages of development inside the patient's body.

ii. Nanobots that destroy brain cancer cells were recently simulated by Loscrí et al. who called them Nano Bee. Nano Bees have the ability to identify cancer cells, eliminate them, and detect and transmit an acoustic signal in the presence of tumours.[28-30] (Figure 2)

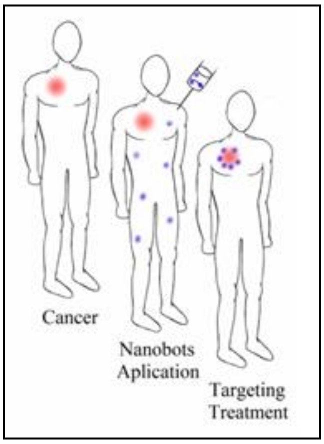

Figure 2.

i. They detect different levels of E-cadherin and beta-catenin as medical targets in primary and metastatic phases, thus helping in target identification and drug delivery.

ii. They also transport the chemicals used in chemotherapy to treat cancer directly at the site. Nanorobot with embedded chemosensor is involved in the modulation of hSGLT3 protein glucosensor activity (protein hSGLT3 – helps to define the glucose levels and serves as a sensor to identify glucose for diabetes patients). Later the significant measured data can then be transferred automatically via the RF signals to the mobile phone carried by the patient. At any time, if the glucose achieves critical levels, the nanorobot emits an alarm through the mobile phone.[17,31-32]

- Surgical nanorobots – Aids in searching pathology and then diagnosing and correcting lesions by nanomanipulation when introduced into the body through the vascular system.[33]
- "Respirocyte" is an imaginary nanorobot, that floats all along in the bloodstream which can mimic the action of the natural hemoglobin-filled red blood cells and can deliver over 236 times more oxygen per unit volume when compared to a natural red cell.[34]
- Artificial Phagocyte (Microbivore) **–** By using the "digest and discharge" protocol, they destroy microbiological pathogens that are found in the human bloodstream.[35]
- Used as Artificial Neurons
- Helps to locate atherosclerotic lesions in blood vessels, mainly in the coronary circulation, and treat them either mechanically, chemically, or pharmacologically.
- Helps in Cell Repair and Lysis via attachment to transmigrating inflammatory cells or white blood cells, to reach inflamed tissues and assist in their healing process.[17]

- Helps in removing debris from wounds reducing the chances of infection.[27]
- Can be used as clottocytes or nanorobotics artificial mechanical platelets to treat patients with hemophilia.[36]
- “pharmacytes”, given by Freitas, are drug-delivery nanorobots that can be used to deliver anti-HIV drugs.[37]
- Aids in detecting Alzheimer’s disease based on the amyloid protein β deposits
- Other medical uses include the treatment of gout, lysing of kidney stones, Brain Aneurysms, and Fetal and Child-Related Disorders (fetal anemia (erythroblastosis fetalis)). The neonatal hemolytic disease also has application in gene therapy i.e., comparing two DNA chains; sensing proteins inside the cell, and replacing chromosomes.[27,38]

B. Dental applications

As aforementioned, by employing the use of nanomaterials, biotechnology including tissue engineering, and ultimately nanorobotics, nanodentistry will facilitate the maintenance of comprehensive oral health advancing a better future.

In dentistry, nanorobots are gaining importance via

- Bring about oral analgesia
- Tooth desensitization
- manipulating the tissue to realign and straighten irregularly arranged teeth
- to enhance the durability of teeth
- also employed to do preventive, restorative, curative procedures i.e., Dental nanorobots could be used to kill caries-causing bacteria or to repair tooth blemishes where decay has developed, by employing a computer to direct these tiny workers in their tasks.[22]

I. APPLICATION IN PERIODONTICS

Nanorobots have numerous applications in Periodontology, which consists of therapy for dentin hypersensitivity, dentition renaturalization, oral health maintenance by means of mechanical dentifrobots, and also in other preventive, restorative and therapeutic procedures.[39]

1. Nanoanaesthesia

A colloidal suspension containing millions of active analgesic microns to which dental nanorobots particles are infused on the patient’s gingiva. Once they lie in proximity to the mucosa or crown, the ambulating nanorobots reach the dentin, by migrating into the gingival sulcus and passing painlessly to the lamina propria or through a 1-3 micrometer thick layer of loose tissue at the CEJ. On reaching the dentin, nanorobots enter the dentinal tubules up to 1-4micron depth and move towards the pulp directed by a combination of chemical gradients, temperature differentials, and even positional navigation, all under the control of a nanocomputer as guided by the dentist. Time taken for nanorobots to reach the pulp from the tooth surface is approximately 100 seconds thereby giving a quick relief of sensitivity.

i.e., Tooth surface $\xrightarrow{\text{100 seconds}}$ pulp

Upon reaching the pulp, they are given an order by the dentist to shut down all the sensations of that particular tooth that requires treatment. Once the procedure is completed, the dentist orders the robots to reinstate all the sensations.[40]

Advantages

- ✓ Renders better and speedy action
- ✓ Reduced patient anxiety as it doesn’t use needles
- ✓ Reduced adverse effects/complications of local anesthesia.
- ✓ Anesthetic effect is fast and completely reversible thus offering both patient and dentist comfort.[24]

2. Management of dentinal hypersensitivity

The most commonly faced dental problem by the patients is Dentinal hypersensitivity which is another area where Nanorobots are useful. Nanorobots are utilized to selectively and precisely occlude tubules in minutes, by making use of native biologic material, thus benefiting the patients with a rapid and permanent cure.[40]

The choice of material is Nanohydroxyapatite (n-HAP). It is gaining importance in the field of dentistry, mainly ascribed to its structural similarity to the crystals of the tooth enamel, and is a biocompatible and bioactive material.

n- HAP-containing toothpaste was found to be advantageous in decreasing dentin hypersensitivity and can be prescribed for dentinal hypersensitivity management. Wang *et al* in their study reported that nano-hydroxyapatite formulations (with or without home-care product association) were as effective as the other treatment approaches in decreasing dentin hypersensitivity.[41]

3. Nanorobotic dentifrices (dentifrobots)

Nanorobotic dentifrices are as small as 1-10 microns and can crawl as fast as 1-10 microns/second, inexpensive, mechanical devices which are safely deactivated when swallowed. Available as mouthwash or toothpaste. Monitors all supragingival and subgingival surfaces at least once a day, metabolizes trapped organic matter into harmless and odorless vapors and performs continuous calculus debridement. Dentifrobots will be able to access previously inaccessible places such as the distal side of third molars, pericoronal flaps etc. These recognize and selectively kill plaque microorganisms, thus minimizing the rate of recolonization onto the clean tooth surfaces. This way it is helpful in maintaining or enhancing proper oral hygiene and also aids in regulating halitosis since bacterial putrefaction is the central metabolic process involved in oral malodor. If such meticulous oral hygiene is performed on a daily basis from an early age, dental caries and gum-related diseases will start diminishing eventually.[17,42-44]

II. Applications In Orthodontics

Tooth alignment – nanorobots lessen the duration of orthodontic therapy by their potential to directly manipulate the periodontal structures including gingiva, periodontal ligament, cementum, and alveolar bone. Thus allowing a quick, painless tooth straightening, rotating, vertical repositioning, and also rapid tissue repair within minutes to hours. As a result, the necessity to wear orthodontic appliances for a longer amount of time is reduced, and patient discomfort is reduced.[45]

III. Tooth Reconstruction and Maintenance

Natural teeth can be grown in vitro and implanted into extraction sockets followed by their integration into the surrounding tissues by developing vascular and neurological networks with the help of nanorobots. By substituting materials like sapphire and diamond for the superficial enamel, reconstructive dental nanorobots can enhance the durability and appearance of teeth. Additionally, they can use tissue-engineered biological materials to excavate dental caries and fill cavities, restoring teeth to their prior shape.

IV. Treatment of Oral Cancer

Nanorobots can be programmed to penetrate cancerous lesions, identify neoplastic cells and destroy them by increasing the intracellular pressure or temperature utilizing focal lasers, microwaves or ultrasonic waves.[46] (Figure 3)

Figure 3: - Nanobot attacking an oral cancer cell.

Advantages & Disadvantages of Nanorobots

1. Nanorobotics is evolving rapidly progressively in the medical field owing to their effectiveness, and comfort, simultaneously lowering the risk and invasiveness significantly.
2. Nanorobotics will help in the early diagnosis or prevention or management of the disease.[47]

Despite their varied applications and numerous advantages, nanorobots have challenges and risks. Following are some of the disadvantages.

1. Expensive initial design.
2. Difficult to Interface, Customize, and has a complicated design
3. Electrical nanorobots are vulnerable to electrical interference from external sources such as radiofrequency(rf) or electric fields, electromagnetic pulse (EMP), and stray fields from other in vivo electrical devices.[33,48-49]

CONCLUSION

Nanodentistry has the potential to be the future of dentistry. All procedures could be carried out by nanobots. Computer-controlled nanorobots will be the mainstay of nanotechnology in periodontal care in the future. Nanorobots have the potential to play an important role in a variety of therapy and prevention techniques, including dentifrice, dental hypersensitivity, and local medication release. These nanorobots prefer to migrate up to the intended location of action and, using the dentist's directions, carry out their pre-programmed action at the site.In fact, nanobots could replace dental assistants. Diagnoses could also be performed by nano-devices that can not only diagnose but also provide a solution in a short amount of time. While some nanobotic technology is already in use, we should see these developments within the next decade or two.

REFERENCES

1. Haridas S, Harish Kumar VV, Sreekanth P, Sanara PP. NANOROBOTS IN PERIODONTICS. DENTAL BITES. 2015 Apr: 17.
2. Nasrollahzadeh M, Sajadi SM, Sajjadi M, Issaabadi Z. An introduction to nanotechnology. InInterface science and technology, 2019 Jan 1; 28: 1-27. Elsevier.
3. Kong LX, Peng Z, Li SD, Bartold PM. Nanotechnology and its role in the management of periodontal diseases. Periodontology, 2000; 2006 Feb; 40(1): 184-96.
4. Jan SM, Mir RA, Behal R, Shafi M, Kirmani M, Bhat MA. Role of nanotechnology in dentistry. Sch J App Med Sci., 2014; 2(2D): 785-9.
5. Moghimi SM, Hunter AC, Murray JC. Nanomedicine: current status and future prospects. The FASEB journal. 2005 Mar; 19(3): 311-30.
6. (Hamissi H, Hamissi Z, Hamissi JH. Nanotechnology in dental practice: current achievement and prospects.)
7. Freitas Jr RA. Nanodentistry. The Journal of the American Dental Association, 2000 Nov 1; 131(11): 1559-65.
8. Jhaveri HM, Balaji PR. The future of dentistry a review. Jr I Prosthetic, 2005; 5: 15–7.
9. Cerofolini G, Amato P, Masserini M, Mauri G. A surveillance system for early-stage diagnosis of endogenous diseases by swarms of nanobots.

Advanced Science Letters, 2010 Dec 1; 3(4): 345-52.
10. Yarin AL. Nanofibers, nanofluidics, nanoparticles and nanobots for drug and protein delivery systems. Scientia Pharmaceutica, 2010 Sep; 78(3): 542.
11. xDalai DR, Gupta D, Bhaskar DJ, Singh N, Jain A, Jain A, Singh H, Kadtane S. Nanorobot: a revolutionary tool in dentistry for next generation. Journal of Contemporary Dentistry, 2014 May 1; 4(2): 106.
12. Gutierrez B, Villalobos Bermúdez C, Corrales Ureña YR, Vargas Chacón S, Vega Baudrit J. Nanobots: development and future.
13. Wang j, hartmann fk , fedorov r. can manmade nanomachines compete with nature biomotors. ACS Nano, 2011; 3(1): 4-9.
14. https://roboticsbiz.com/nanorobots-key-components-and-substructures/
15. Strickland J. How nanorobots will work. How Stuff Works, 2010; 2: 14-8.
16. Saxena S, Pramod BJ, Dayananda BC, Nagaraju K. Design, architecture and application of nanorobotics in oncology. Indian Journal of Cancer, 2015 Apr 1; 52(2): 236.
17. Abhilash M. Nanorobots. Int J Pharma Bio Sci., 2010; 1: 1–10.
18. Cavalcanti A, Shirinzadeh B, Zhang M, Kretly LC. Nanorobot hardware architecture for medical defense. Sensors, 2008 May 6; 8(5): 2932-58.
19. Hogg T, Freitas Jr RA. Chemical power for microscopic robots in capillaries. Nanomedicine: Nanotechnology, Biology and Medicine, 2010 Apr 1; 6(2): 298-317.
20. Sa./c/
21. Freitas RA. Nanomedicine basic capabilities, George Town TX: Landes Bioscience, 1999; 345-47.
22. Babel, Mathur. Nanorobotics- Headway towards dentistry. Int J. Res. Sci Tech., 2011; 1: 1-9.
23. Cavalcanti A. Manufacturing technology for medical nanorobots. InAsia Pac Nanotechnol Forum News J., 2007; 6: 8-13.
24. Freitas Jr RA. What is nanomedicine?. Nanomedicine: Nanotechnology, Biology and Medicine, 2005 Mar 1; 1(1): 2-9.
25. Shmulevich I, Dougherty ER. Modeling genetic regulatory networks with probabilistic Boolean networks. Genomic Signal Processing and Statistics. 2005; 241-79.
26. Paul P. NANOROBOTICS, THEIR MAKEUP & APPLICATIONS–A REVIEW.
27. Nanorobots–A sensor based control applied to Nanomedicine Sonalika Patro, IJCTPR, 2015; 3(1): 775–785.
28. Venkatesan M, Jolad B. Emerging Trends in Robotics and Communication Technologies (INTERACT). InInternational Conference on: IEEE, 2010; 258-264.
29. Cavalcanti A, Freitas RA. Nanorobotics control design: A collective behavior approach for medicine. IEEE Transactions on Nanobioscience, 2005 May 31; 4(2): 133-40.
30. Neto AM, Lopes IA, Pirota KR. A Review on Nanorobotics. Journal of Computational and Theoretical Nanoscience, 2010 Oct 1; 7(10): 1870-7.
31. Patel GM, Patel GC, Patel RB, Patel JK, Patel M. Nanorobot: a versatile tool in nanomedicine. Journal of drug targeting, 2006 Jan 1; 14(2): 63-7.
32. Cavalcanti A, Shirinzadeh B, Kretly LC. Medical nanorobotics for diabetes control. Nanomedicine: Nanotechnology, Biology and Medicine, 2008 Jun 1; 4(2): 127-38.
33. Cavalcanti A. Assembly automation with evolutionary nanorobots and sensor-based control applied to nanomedicine. IEEE Transactions on Nanotechnology, 2003 Jun 20; 2(2): 82-7.
34. Freitas Jr RA. A mechanical artificial red cell: exploratory design in medical nanotechnology. Artificial Cells, Blood Substitutes, and Immobilization Biotechnology, 1998; 26: 411-30.
35. Freitas Jr RA. Microbivores: artificial mechanical phagocytes using digest and discharge protocol. J Evol Technol, 2005 Apr; 14(1): 54-106.
36. Parmar DR, Soni JP, Patel AD, Sen D. Nanorobotics in advances in pharmaceutical sciences. Int J Drug Dev and Res, 2010 Apr; 2: 247-56.
37. Freitas Jr RA. The ideal gene delivery vector: chromallocytes, cell repair nanorobots for chromosome replacement therapy. Journal of evolution & technology, 2007 Jun 1; 16(1).
38. Cantín M, Vilos C, Suazo I. Nanoodontologia: El futuro de la Odontología basada en sistemas nanotecnologicos. International journal of odontostomatology, 2010 Sep; 4(2): 127-32.
39. Shetty NJ, Swati P, David K. Nanorobots: Future in dentistry. The Saudi dental journal, 2013 Apr 1; 25(2): 49-52.
40. Nagpal A, Kaur J, Sharma S, Bansal A, Sachdev P. Nanotechnology-the Era Of Molecular Dentistry. Indian journal of dental sciences, 2011 Dec 1; 3(5).
41. Wang L, Magalhães AC, Francisconi-Dos-Rios LF, Calabria MP, Araújo DF, Buzalaf MA, Lauris JR, Pereira JC. Treatment of dentin hypersensitivity using nano-hydroxyapatite pastes: a randomized three-month clinical trial. Operative dentistry, 2016; 41(4): E93-101.
42. Ahmed W, Subramani K, editors. Emerging Nanotechnologies in Dentistry: Processes, Materials and Applications. William Andrew; 2012.
43. Satyanarayana T, Rai R Nanotechnology: The future. Journal of Interdisciplinary Dentistry, 2012; 1: 93-100.
44. Gambhir RS, Sogi GM, Nirola A, Brar R, Sekhon T, Kakar H Nanotechnology in dentistry: Current achievements and prospects. J of Orofacial Sciences, 2013; 5: 9-14
45. Kohli P, Martin CR Smart nanotubes for biomedical and biotechnological applications. Drug News Prospect, 2003; 16: 566-573.

46. Lumbini P, Agarwal P, Kalra M, Krishna KM. Nanorobotics in dentistry. Ann Dent Spec, 2014 Jul; 2: 95-6.
47. Shashirekha G, Jena A, Mohapatra S. Nanotechnology in Dentistry: Clinical Applications, Benefits, and Hazards. Compendium of continuing education in dentistry (Jamesburg, NJ: 1995), 2017 May 1; 38(5): e1-4.
48. Moore SK. Just one word-plastics. Ieee Spectrum, 2002 Sep; 39(9): 55-9.
49. Cavalcanti A, Rosen L, Kretly LC, Rosenfeld M, Einav S. Nanorobotic challenges in biomedical applications, design and control. InProceedings of the 2004 11th IEEE International Conference on Electronics, Circuits and Systems, 2004. ICECS, 2004. 2004 Dec 15; 447-450. IEEE.