AMERICAN JOURNAL OF PHARMTECH RESEARCH
Journal home page: http://www.ajptr.com/

Nanorobots Recent and Future Advances in Cancer or Dentistry Therapy- A Review

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ABSTRACT

Nanorobots are considered to be the next generation of Nanomachine which deals with design and construction of devices at an atomic, molecules or cellular level. These hypothetical Nanorobots will be extremely small and would transverse inside the human blood. In 2015 there were 11,48,692 cases of cancer in India. The present methods for the treatment of cancer are not that effective as 99% of chemotherapy drugs do not reach the cancer cells. However, Nanorobots which are roughly 100 times smaller than human tissues could do this and hence creates a huge area for exploration in the field of biomedical research. As scientists predict in coming years cancer will be a chronic but manageable disease. Especially in the treatment of cancer, Cerebral Aneurysm, kidney stones removal, also to remove the defected part in our DNA structure and some other treatments that have the greatest aid to save human lives. This paper guides to the recent research on Nanorobots in the biomedical applications. Treatment possibilities might include the application of nanotechnology to local anesthesia, dentition denaturalization, the permanent cure for hypersensitivity, complete orthodontic realignment in a single visit, covalently bonded diamondized enamel, and continuous oral health maintenance using mechanical dentifrobots. Nanorobots can offer a number of advantages in drug delivery over present methods. In addition, the current study also involves the future aspects of Nanorobots.

Keywords: Nanorobots, Cancer chemotherapy, Anticancer Drugs, dentistry, Dental implants

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Received 04 June 2019, Accepted 14 June 2019

Please cite this article as: Bhatt P *et al.*, "Nanorobots" Recent and Future Advances in Cancer or Dentistry Therapy- A Review.. American Journal of PharmTech Research 2019.

INTRODUCTION

Nanotechnology is the investigation, design, creation, combination, control, and utilization of materials, gadgets, and frameworks at the nanometre scale (One meter comprises of 1 billion nanometres). It is winding up progressively critical in fields like building, farming, development, microelectronics, and healthcare [1].

Nanorobots are nano devices that will be utilized to maintain and securing the human body against pathogens [2]. Although a few analysts trust that it is a logical transformative structure that did not create until the late 1980s, proof of nanotechnology goes back to 1959. Others trust that people have accidentally utilized nano technological strategies for a great many years, maybe significantly more. Be that as it may, nanotechnology is still crisp, giving another field to logical research [3]. Recent advances in atomic science and materials science have displayed a combination of supra sub-atomic or nanoparticle-based specialists that play out an assortment of complex theranostic actions, for example, self-governing coordinated development [4], modern Boolean-rationale based biosensing, and so forth [5– 6].

There are two fundamental sorts of nanobots; constructing agents and self-replicators. Constructing agents are basic cell-molded nanobots that can decipher particles or molecules of various sorts, and are constrained by explicit specific projects. Self-replicators are on a very basic level constructing agents that are fit for copying themselves at an exceptionally huge, quick rate; it is this kind of duplication that guides the development of extensive scale applications or sending of nanobots for substantial scale undertakings [7].

The controlling of the nanorobots should be possible by utilizing neighborhood glucose and oxygen for vitality. In a clinical situation, another alternative would be remotely provided acoustic vitality. Different wellsprings of vitality inside the body can likewise be utilized to supply the fundamental vitality for the gadgets. They will have straightforward locally available PCs equipped for performing around 1000 or fewer calculations for every second [8].

Nanofabrication and assembly

Right now, researchers have prevailing to grow just organic Nano robotic frameworks, though, artificial Nano robots are as yet an idea that is being investigated forcefully. The key test in the advancement of these frameworks is their manufacture and gathering at Nano-scale. Different systems are being created for Nano control including scanning probe microscopy (SPM) and Atomic Force Microscopy(AFM) as a few promising techniques for little scale improvement of Nano devices [9, 10].

They will have a measurement of about 0.5 to 3 microns and will be built out of parts with measurements in the scope of 1 to 100 nanometres. Carbon will probably be the vital component containing the heft of a restorative nanorobot, likely as precious stone or fullerene nano composites. Numerous other light components, for example, hydrogen, sulphur, oxygen, nitrogen, fluorine, silicon, and so on will be utilized for extraordinary purposes in nanoscale gears and other components [11].

IMPORTANCE OF NANOROBOTS FOR HEALTH

Cancer treatment

Drug Delivery Systems for Anticancer Drugs

The Paclitaxel is directed by intravenous infusion and assumes a job in the treatment of breast cancer. Among the unfavorable impacts experienced some genuine, are bone marrow concealment and combined neurotoxicity [12].

Camptothecin is utilized in the treatment of neoplasias because of restraint of sort I topoisomerases, a fundamental enzyme for cell replication hereditary material [13]. Clinical trials are ponders in people to gauge the parameters of security and adequacy of new drugs, it is basic for the landing of new therapeutic options in the market [14]. In any case only a couple of DDS achieved further developed phases of clinical assessment, for example, fundamentally comprising of doxorubicin, paclitaxel, camptothecin and platinum edifices [15]. Doxorubicin was stacked on the outside of Single-Walled Carbon Nanotubes (SWNTs) [16]. The look for biocompatible materials and can fill in as a Drug Delivery System is dependably the focal point of nanotechnology. Nanoparticle HA (Hydroxyapatite) - a noteworthy constituent of bone and teeth were utilized to convey Paclitaxel (Tax), an antineoplastic specialist and the outcomes propose great desire with treatment beginning from hydrophobic drugs [17].

Limitations of Chemotherapy

The Conventional chemotherapeutic agents work by decimating quickly separating cells, which is the primary property of neoplastic cells. This is the reason chemotherapy additionally harms ordinary sound cells that separate quickly, for example, cells in the bone marrow, macrophages, digestive tract, and hair follicles [18]. This outcomes in like manner symptoms of most chemotherapeutic agents which incorporate myelosuppression (diminished the generation of white platelets causing immunosuppression), mucositis (irritation of the coating of the digestive tract), alopecia (balding), organ brokenness, and even Nanorobotics in Drug Delivery Systems for Treatment of Cancer: A Review 173 anemia or thrombocytopenia. These symptoms now and then force dose decrease, treatment postponement, or discontinuance of the given treatment [19].

Customary chemotherapeutic agents frequently get washed out from the dissemination being immersed by macrophages. Therefore they stay in the flow for a brief timeframe and can't collaborate with the malignant cells making the chemotherapy totally incapable. The poor solvency of the drugs is additionally a noteworthy issue in ordinary chemotherapy making them unfit to enter the organic films [20].

Treatment

Cancer can be effectively treated with current phases of restorative advances and treatment devices with the assistance of the nanorobotics. Decide the definitive factor to chances for a patient with cancer to endure is: the means by which prior it was analyzed, another vital angle to accomplish a fruitful treatment for patients is the advancement of proficient focused on drug delivery to diminish the symptoms from chemotherapy [21]. Cancer could be characterized as the gathering of diseases described by the uncontrolled development and spread of anomalous cells in the body is the thing that characterizes cancer, and the quantity of people influenced every year keeps on climbing [22]. At present, the nanorobots are customized to perceive 12 kinds of cancer cells. Also, the sub-atomic engines of these gadgets can change their compliance under outside boosts of bright light and drill through cell bilayers to initiate rot of undesirable cells or to acquaint adjusted species and drugs with specifically target sites [23]. A few techniques created by researchers planned to combine drug-stacked nanoparticles where the helpful agents will cling to the cancer cell and will discharge the drug locally. The connection of nanoparticles to cancer cells can be acknowledged by the RNA strands situated to the outside of nanoparticles [24]. The researchers are centred on the combination of natural, inorganic, and half breed nanorobots. Liposomes, polymers, micelles, quantum spots, metallic nanoshells, gold nanoparticles, and carbon nanotubes are a few classes of natural and inorganic particles with a lot of enthusiasm for nanorobot structure. Likewise, the outside of nanorobots might be synthetically prepared to upgrade soundness, dissolvability, and biocompatibility properties or to enable to distinguish varieties in the encompassing condition's status. Remote control and situating of drug-delivery systems establish a potential course for negligibly intrusive focused on treatment. X-ray guided nanocapsules speak to a potential.

A precursor for nanorobots [25]

This way to deal with control nanorobot development is favored due to the non-intrusive character of the strategy and permits synchronous exact invitation and following of the nanodevices. Along these lines, the flow innovations and treatment instruments of pharmaceutics can structure an item to treat patients with genuine diseases. Be that as it may, legitimate treatment is controlled by the

phase of cancer and the likelihood of planning an effective focused on the drug-delivery system [26]. Specific control of the helical type of nanorobots addresses the gadgets for versatile radiation treatment in cancer treatment dependent on particular exchanging of radioactive sources spread in a tumor region. Likewise, nanorobots can utilize lasers or ultrasonic sources to counter cancerous cells. Inserted compound biosensors on the nanorobot surface can be utilized to recognize the nearness of tumor cells in the beginning period of the illness. More often than not, the nanorobots are infused into the circulation system in one portion with the objective of checking and obliterating the cancer cells without influencing solid ones. Light-controlled nano-submarines were tried utilizing engineered natural circuits dependent on ribonucleic corrosive to identify sickness causing agents and to deliver drugs [27]. Considering the properties of Nanorobots to explore as blood-borne gadgets, they can help on such critical parts of cancer treatment. Nanorobots with installed compound biosensors can be utilized to perform the discovery of tumor cells in beginning times of improvement inside the patient's body. Coordinated nanosensors can be used for such an assignment so as to discover the power of E-cadherin signals. In this way, an equipment engineering dependent on nano bioelectronics is depicted for the use of nanorobots for cancer treatment [28]. Considering the properties of nanorobots to explore as bloodborne gadgets, they can help essential treatment procedures of complex diseases in early determination and brilliant drug delivery [29]. A nanorobot can give a proficient early analysis of cancer and help with shrewd chemotherapy for drug delivery. Nanorobots as drug transporters for auspicious measurements regimens permits keeping up the concoction mixes for a more drawn out time as vital into the circulatory system course, giving anticipated pharmacokinetic parameters to chemotherapy in hostile to cancer medicines [30-32]. It maintains a strategic distance from the current coming about extravasations towards non-reticulo endothelial-found cancers with the high degenerative symptoms amid the chemotherapeutic procedure [33]. Nanorobots with concoction Nano biosensors can be customized to recognize distinctive dimensions of E-cadherin and beta-catenin as medicinal focuses on essential and metastatic stages [34, 35], helping target distinguishing proof and drug delivery. A definitive factor to decide the odds for a patient with cancer to endure is: the way prior it was analyzed what implies, if conceivable, cancer ought to be identified at any rate before the metastasis has started. Another critical perspective to accomplish a fruitful treatment for patients is the advancement of productive focused on drug delivery to diminish the symptoms from chemotherapy. Considering the properties of nanorobots to explore as blood-borne gadgets, they can help on such critical parts of cancer treatment. [36].

Applications in clinical dentistry

Nanoanesthesia When nanotechnology or nanorobots are utilized to instigate anesthesia, the gingiva of the patient is imparted with a colloidal suspension containing a large number of dynamic, pain relieving, micron measured dental robots that react to enter provided by the dental specialist. Nanorobots in contact with the outside of the crown or mucosa can achieve the mash by means of the gingival sulcus, lamina propria, or dentinal tubules. Once in the mash, they shut down all sensations by setting up command over nerve drive traffic in any tooth that requires treatment. After fulfillment of treatment, they reestablish this sensation, consequently giving the patient anxiety free and needleless solace. The anesthesia is quick acting and reversible, with no reactions or complexities related to its uses [37]. In a maxillofacial medical procedure, a few nanorobots have been utilized as route gadgets with accomplishment in the treatment of post-horrible distortions, arthroscopy of the mandibular joint, punctures, and biopsies. Dental specialists have proposed that nanomachines could convey sedative or drugs in the treatment of dentine extreme touchiness, improvement of teeth sturdiness, too for orthodontic medications so as to control the tissue to realign and rectify a sporadic arrangement of teeth [38]. The principle utilization of dental robots incorporate the likelihood of prompting anesthesia and osseointegration, to convey dentine tubules for blocking tooth excessive touchiness, adding to orthodontic medicines by permitting effortless tooth up righting, pivoting, and vertical re-positioning or going about as nanoneedles. So also, the nanorobots can be utilized as bearers for nano solutions which contain holding agents, impression materials, nanofillers, for example, those of vinylpolysiloxanes, bone substitution materials, for nanoencapsulation of helpful agents into polymeric nanocapsules, to shape nanocomposites with antibacterial and brightening agents so as to improve clean capacity and tooth style. Polymeric materials have been created with fantastic properties for dental applications. Bionanocomposites with polymers are set up with biocompatible collagen, alginate, silk, poly(lactic corrosive), poly(glycolic corrosive), poly(lactic-co-glycolic corrosive), poly(caprolactone), and inorganic materials, for example, bioactive glass nanoparticles, attractive nanoparticles, carbon nanotubes, hydroxyapatite, silver or gold nanoparticles, graphene oxide, titanium oxide, and silica nanoparticles. Dental nanorobots are prearranged to utilize explicit motility components to creep or swim through the circulatory system, to detect and control encompassing alterations, to accomplish safe infiltration into the cells, and to utilize any of a large number of procedures to screen, interfere, or modify nerve-motivation traffic in individual nerve cells continuously. Nano arrangements since they produce interesting and dispersible nanoparticles, Nano arrangements can be utilized as holding agents. Homogeneity is guaranteed, in light of the fact that the cement is blended splendidly unfailingly. Nanoparticles have likewise

have resulted as a cleaning arrangement in the type of Nano sized emulsified oil beads that besiege pathogens [39]. Bone substitution materials Bone is a natural nanostructure that is made out of natural mixes (for the most part collagen) and fortified inside natural ones. Nanotechnology expects to copy this common structure for orthopedic and dental applications and, all the more especially, for the improvement of nano bone. Nanocrystals show a loose miniaturized scale structure, with nanopores arranged between the precious stones. The surfaces of the pores are changed with the end goal that they adsorb protein, because of the expansion of silica atoms. Bone imperfections can be treated by utilizing the hydroxylapatite (HA) no particles [40].

Dental implants

Structure, chemistry, and biocompatibility the determining factors for successful osseointegration are surface contact area and surface topography. However, bone bonding and stability also play a role. Bone growth with increased predictability can be effectively expedited with implants by using nanotechnology. The addition of nanoscale deposits of hydroxyapatite and calcium phosphate creates a more complex implant surface for osteoblast formation [41].

DNA Nanorobot-based Thrombin Delivery to Tumor Vessels

The DNA origami procedure was introduced by Rothemund in 2006. An ideal DNA origami structure is developed by a long framework single-stranded DNA atom collapsed into a subjective design using several staple strands that fix the platform's adaptation [42, 43]. The DNA origami technique empowers a discerning plan and generation of DNA nanostructures with all around defined homogeneous geometries, exact spatial location capacity, and stamped bio-compatibility. DNA origami is a clean slate that can contain numerous remedial cargoes and tumor targeting ligands with normally planned numbers and examples anyplace on the whole addressable nanostructure. These exceptionally favorable circumstances of DNA origami structure have presented them with different bio-medicinal applications. For instance, a dynamic hexagonal origami barrel DNA nanostructure was made to convey and definitely transport gold nanoparticles and counteracting agent Fab sections to target cells. In a modified way, this amazing DNA Nano gadget showed the capacity of DNA origami to detect cell surface inputs and trigger cell enactment in-vitro [44].

In view of the burgeoning advancements of DNA origami procedure, a cylinder formed DNA Nanorobot (19 nm 90 nm) was customized to specifically convey thrombin into tumor vessels to induce thrombosis for tumor treatment [45].

CONCLUSION

While several tasks, such as targeted drug delivery, cancer therapy, or tissue engineering have been presented, various challenges need to be addressed before translating the small-scale robots from in vitro studies to clinical applications. Nanotechnology as a diagnostic and treatment tool for patients with cancer and diabetes showed how actual developments in new manufacturing technologies are enabling innovative works which may help in constructing and employing nanorobots most effectively for biomedical problems. Nanorobots applied to medicine hold a wealth of promise from eradicating disease to reversing the aging process (wrinkles, loss of bone mass and age-related conditions are all treatable at the cellular level); nanorobots are also candidates for industrial applications. They will provide personalized treatments with improved efficacy and reduced side effects that are not available today. They will provide combined action drugs marketed with diagnostics, imaging agents acting as drugs, surgery with instant diagnostic feedback. Nonetheless, the positive results in nanorobots have brought in new hope to cancer research. Nanotechnology in dentistry still faces many challenges. Conflicting views remain regarding the use of nanorobots in vivo. These views need to be addressed before nanotechnology can be incorporated into the armamentarium of modern medicine. While many scientific teams with medical, pharmaceutical, or engineering backgrounds have designed nanorobots small enough to enter the bloodstream, this domain is still a fantasy due to the lack of a well-established technology for manufacturing systems specifically for biomedical applications; however, in the longer term, it is possible that all these limitations will be overcome and thereby nanorobots may become ubiquitous in medicine.

ACKNOWLEDGMENT

The author extends sincere appreciation to the Vivek College of technical education Bijnor U.P

AUTHOR CONTRIBUTION

Mr. Pankaj Bhatt designed the review and collected the information’s from various sources.

REFERENCE

1. Debjit B, Chiranjib, Margret chandira R, Jayakaret B. Role of nanotechnology in novel drug delivery system. J Pharm Sci and Tech, 2009; 1: 20-35.
2. 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;3:4: 345–352.
3. Freitas Jr, R.A., 2005. What is nanomedicine? Nanomed. Nanotech. Biol. Med. 1, 2–9.
4. J. Wang, Nanomachines: Fundamentals and Applications, John Wiley & Sons, 2013.

5. S.M. Douglas, I. Bachelet, G.M. Church, A Logic-Gated Nanorobot for Targeted Transport of Molecular Payloads, Science 335 (2012) 831–834.
6. M.P. Nikitin, V.O. Shipunova, S.M. Deyev, P.I. Nikitin, Biocomputing based on particle disassembly, Nat. Nanotechnol. 9 (2014) 716–722.
7. Y. Amir, E. Ben-Ishay, D. Levner, S. Ittah, A. Abu-Horowitz, I. Bachelet, Universal computing by DNA origami robots in a living animal, Nat. Nanotechnol. 9 (2014) 353–357.
8. R. Freitas, Journal of Computational and Theoretical Nanoscience, 2005 Vol.2, pp. 1–25.
9. Yarin A. L. Urbanke, C., Manstein "Nanofibers, nanofluidics, nanoparticles and nanobots for drug and protein delivery systems". Scientia Pharmaceutica Central European Symposium on Pharmaceutical Technology 2010;78:3:542.
10. A.A.G. Requicha, Nanorobots, NEMS and Nanoassembly. Proceedings of theIEEE,2003, 9, 1922-1926.
11. N.A. Weir, D. P. Sierra, J. F. Jones, A Review of Research in the Field of Nanorobotics; Sandia National Laboratory, Sandia Corporation: Albuquerque, New Mexico, 2005.
12. Wang, J., Hartmann, F. K., Fedorov R."Can Man-Made Nanomachines Compete with Nature Biomotors". ACS Nano 2011;3(1): 4–9.
13. Rang, H. P., Ritter, J. M., Flower, R. J. and Henderson, G. 2015. Rang & Dale's Pharmacology 8th Editio. Churchill Livingstone, 776.
14. Golan, D. E., Tashjian Jr., A. H., Armstrong, E. J. and Armstrong, A. W. 2011. Principles of Pharmacology: The Pathophysiologic Basis of Drug Therapy. LWW; 3rd edition (June 24, 2011), 976.
15. Brasil Acessed 2015, Publicadas novas normas para pesquisa clínica., Agência Nacional de Vigilância Sanitária-Anvisa. Accessed May 24, 2016.
16. Kratz, F. and Warnecke, A. 2012. "Finding the Optimal Balance: Challenges of Improving Conventional Cancer Chemotherapy Using Suitable Combinations with Nano-Sized Drug Delivery Systems." J Control Release 164: 221-35.
17. Zeeshan, M. A., Pané, S., Youn, S. K., Pellicer, E., Schuerle, S., Sort, J., Fusco, S., Lindo, A. M., Park, H. G. and Nelson, B. J. 2013. "Graphite Coating of Iron Nanowires for Nanorobotic Applications: Synthesis, Characterization and Magnetic Wireless Manipulation." Advanced Functional Materials 23 (7): 823-31.

18. Watanabe, K., Nishio, Y., Makiura, R., Nakahira, A. and Kojima, C. 2013. "Paclitaxel-Loaded Hydroxyapatite/Collagen Hybrid Gels as Drug Delivery Systems for Metastatic Cancer Cells." International Journal of Pharmaceutics 446 (1-2): 81-6.
19. Zhao, G. and Rodriguez, B. L. 2013. "Molecular Targeting of Liposomal Nanoparticles to Tumor Microenvironment." International Journal of Nanomedicine 8: 61-71.
20. Coates, A., Abraham, S., Kaye, S. B., Sowerbutts, T., Frewin, C., Fox, R. M. and Tattersall, M. H. 1983. "On the Receiving End--Patient Perception of the Side-Effects of Cancer Chemotherapy." European Journal of Cancer & Clinical Oncology 19 (2): 203-8.
21. Mousa, S. A. and Bharali, D. J. 2011. "Nanotechnology-Based Detection and Targeted Therapy in Cancer: Nano-Bio Paradigms and Applications." Cancers 3 (3): 2888-903.
22. Garcia-Lopez, V., Chen, F., Nilewski, L.G., Duret, G., Aliyan, A., Kolomeisky, A.B., et al., 2017. Molecular machines open cell membranes. Nature 548, 567-572.
23. Nano RNA Delivery. MIT Technology Review. Available at: https://www.technologyreview.com/s/410047/nano-rna-delivery/. Accessed 10 October 2017.
24. Vartholomeos, P., Fruchard, M., Ferreira, A., Mavroidis, C., 2011. MRI-guided nanorobotic systems for therapeutic and diagnostic applications. Annu. Rev. Biomed. Eng. 13 (1), 157-184.
25. Fisher, B., 2008. Biological research in the evolution of cancer surgery: a personal perspective. Cancer Res. 68 (24), 10007-10020.
26. Green, A.A., Kim, J., Ma, D., Silver, P.A., Collins, J.J., Yin, P., 2017. Complex cellular logic computation using ribocomputing devices. Nature 548, 117-121.
27. R. Kumar et al., International Journal of Scientific Research Engineering & Technology (IJSRET), 2014 Vol. 3, Issue 8. ISSN: 2278 – 0882.
28. World Health Organization Accessed 2015, Cancer. Accessed May 31, 2016. http://www.who.int/cancer/en/
29. A source of the internet at http://www.biotechnologyforums.com/thread-1863.html.
30. Freitas, R. A. 2006. "Pharmacytes: An Ideal Vehicle for Targeted Drug Delivery." Journal of Nanoscience and Nanotechnology 6 (9-10): 2769-75.
31. Bhat, A. S. 2014. "Nanobots: The Future of Medicine." International Journal of Engineering and Management Sciences 5 (1): 44-9.

32. Mutoh, K., Tsukahara, S., Mitsuhashi, J., Katayama, K. and Sugimoto, Y. 2006. "Estrogen-Mediated Post Transcriptional Down-Regulation of P-Glycoprotein in MDR1-Transduced Human Breast Cancer Cells." Cancer Science 97 (11): 1198-204.
33. Lagzi, I. 2013. "Chemical Robotics – Chemotactic Drug Carriers." Open Medicine 8 (4): 377-82.
34. Xu, X., Kim, K. and Fan, D. 2015. "Tunable Release of Multiplex Biochemicals by Plasmonically Active Rotary Nanomotors." Angewandte Chemie (International ed. in English) 54 (8): 2525-9.
35. Couvreur, P. 2006. "Nanotechnologies for Drug Delivery: Application to Cancer and Autoimmune Diseases." Progress in Solid State Chemistr 34 (2): 231-5.
36. Janda, E., Nevolo, M., Lehmann, K., x Sci. 1 (3), 16-20.
37. S. Mathur et al., National Conference on Synergetic Trends in engineering and Technology (STET-2014). International Journal of Engineering and Technical Research ISSN: 2321086911.
38. Freitas, R.A., 2000. Nanodent. J. Am. Dent. Assoc. 131 (3), 1559–1566.
39. Rothemund, P.W.K. (2006) Folding DNA to create nano-scale shapes and patterns. Nature 440, 297–302.
40. Kuzuya, A. and Komiyama, M. (2010) DNA origami: fold, stick, and beyond. Nanoscale 2, 309–321.
41. Hong, F. et al. (2017) DNA origami: scaffolds for creating higher order structures. Chem. Rev. 117, 12584–12640.
42. Douglas, S.M. et al. (2012) A logic-gated nanorobot for targeted transport of molecular payloads. Science 335, 831–834.
43. Li, S. et al. (2018) A DNA nanorobot functions as a cancer therapeutic in response to a molecular trigger in vivo. Nat. Biotechnol. 36, 258–264.