Applications of nanorobotics *in vivo* and commercialization prospects for clinical uses

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ABSTRACT

Because of their unique capacity to move and execute complicated tasks at tiny sizes, medical nanorobotics hold a lot of potential for improving medical diagnosis and therapy. Nonetheless, the field's greatest hurdle is its effective translation into broad patient usage. We critically examine the cutting-edge of existing *in vivo* methods and analyse current and future commercialization prospects. Despite the fact that no "killer application" has yet to emerge to drive quick commercialization, recent technical achievements have resulted in the effective *in vivo* functioning of medical nanorobots. We also discuss how standardised nanorobotics report summaries is critical not just for improving research quality but also for reducing investment risk in their eventual commercialization.

Key Words: *Nanorobotics; Nanorobotics.*

INTRODUCTION

Consider a world when cells-sized robots work within our bodies. This may seem like something out of an Isaac asim--ov science fiction tale or a Richard Feynman visionary lecture, but nanorobotics may soon play a significant role in medicine. All nano to micron sized devices capable of converting power sources into kinetic energy are referred to as medical nanorobots. The major focus is on three types of powered nanorobots. As the engine, nanorobot biohybrid systems combine synthetic nanostructures with motile microorganisms. Asymmetric catalytic engines are used in chemically propelled nanorobots to transform chemical fuels into movement. External energy inputs (e.g., magnetic, ultrasonic) are converted into translational motion by physically driven nanorobots using engine geometry and material designs.

At the laboratory scale, the ability of nanorobots to accomplish various tasks has been established, with reports of their usage for a variety of proof-of-concept applications, including targeted cargo delivery, fluid mixing, and physical manipulation of tiny items. Medical nanorobot clinical objectives are still beyond nanotechnology and bioengineering's existing capabilities. Nonetheless, recent technological advances have resulted in the effective in vivo functioning of medical nanorobots, demonstrating first proofs of concept for biopsy, delivery, healing, and retention.

Because of safety issues and the intricacy of functioning within the human body, these technical advancements are still difficult to translate into effective therapeutic therapy. This study focuses on current advancements in the use of nanorobotics in vivo, as well as initiatives to commercialise and transfer laboratory findings into clinical applications. While there have been multiple nanorobot studies that have covered power and actuation principles, manufacturing techniques, and applications, none of these reviews have addressed the critical emergent clinical translations and prospective commercial usage. Nanorobotics, we believe, will be the next frontier in therapy and diagnostics, possibly benefiting human health by allowing for innovative therapies that would otherwise be difficult to obtain.

in vivo NANOROBOTIC APPLICATIONS

In comparison to the enormous number of in vitro proofs of concept, the uses of nanorobots for medicinal reasons in animal models are currently restricted. The growth of cumulative in vivo nanorobotic publications, as well as the high impact factor of the journals in which they are published, both witness to the development in medical applications for nanorobots, as well as the promising level of interest within the scientific community. Although there are a variety of methods for powering nanorobots, we found that only biohybrid (20%), chemical (30%), and physical (50%) systems have been deployed within living animals.

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THERAPEUTIC AND IMAGING AGENTS FOR CANCER THERAPY

The in vivo investigations are broken down into parts based on their clinical goal or research focus. When compared to passive diffusion approaches, medical nanorobotics have a lot of promise for delivering medications with greater precision and speed. In general, in vivo applications have been motivated in this direction. As a result, current in vitro breakthroughs in nanorobotic chemotaxis and material research employing stimuli induced drug release have aided targeted delivery. Magnetically directed nanorobots, for example, were utilised to administer fluorouracil medicine to a mouse model to reduce tumour development. The nanorobotic platform was able to distribute a large volume of the therapeutic agent in a targeted area of the tumour since the released medication was externally activated. Biohybrid nanorobots have also been utilised to deliver payloads to specific locations within living animals. Attached nanoparticles with a payload of genes and proteins were delivered to a mouse using Listeria monocytogenes. Differential luminescence generated inside various animal organs was utilised to measure gene expression using these payloads. Magnetotactic bacteria, which create magnetic iron oxide nanoparticles spontaneously, have been combined with medicinal payload-loaded liposomes in vitro. These modified bacteria were recently used to deliver drug-loaded liposomes in vivo to a mouse tumour location utilising an external magnetic field.

TRANSPORT AND RELEASE OF CELLS

Nanorobots have also been utilised to transfer stem cells to damaged areas in order to restore tissue. Magnetically directed microrobots have been used to transport and deliver live cells to specific bodily locations. In vivo transport and proliferation of HeLa cells in a nude mouse model showed that the transported cells may be released from the microrobot and proliferate in the surrounding tissues. These applications show that nanorobots may be used as platforms for regenerative medicine and cell-based treatment, and that they could be especially valuable as people age and their organs and systems fail.

The goal of medical nanorobotics is to deliver therapeutic payloads to a specific spot while also keeping them there for as long as feasible. Wang's lab has proposed using biodegradable zinc and magnesium-powered microrobots that use gastric and intestinal fluids as fuel to increase cargo retention in the stomach and intestinal tissues in this approach. The pH neutralisation of gastric fluid and the treatment of a bacterial illness in the stomach have both been achieved using these retention platforms. The microrobot's retention might be explained by direct penetration of the surrounding tissue, or by an improvement in mass transport and nucleation caused by the gas bubbles formed as a mode of movement for the microrobot. Magnesium-based microrobots have also been constructed with built-in delay activation, employing polymeric enteric coatings that initiate microrobot movements dependent on their thickness or the pH of the surrounding environment. The polymeric covering only dissolves at the neutral pH seen in intestinal fluids, resulting in microrobot igniting that is confined. The microrobots can be selectively retained in distinct target areas of the gastrointestinal track due to the thickness of the coating. Microrobots were recently integrated/loaded into a pill matrix in order to streamline their administration using current pharmaceutical methods. In general, magnesium-based microrobots might be beneficial in medical applications that need autonomy and simplicity.

WOUND HEALING

For detecting and mending wounds, the human body contains a variety of processes and biological triggers. However, when the wound is bleeding profusely or there aren't enough localised coagulant substances in the target site, these biological processes may fall short. Medical nanorobotics are working in this approach, with the goal of simulating such systems through active delivery for quick and effective wound healing. The delivery of thrombin to stop the bleeding of wounds in the vasculature of mouse and pig models has been described using chemically driven calcium carbonate-based microrobots. A mixture of lateral propulsion, buoyant rise, and convection was used in the distribution mechanism. Another method described was the employment of locomotive microrobots for laser-based wound closure.

BIOPSY

Other in vivo applications with possible medical consequences are those aimed at biopsies and surgery. Various in vitro systems for precision nanoscale surgery have been developed, however they have yet to be transferred to in vivo models. Nanorobotics, on the other hand, might be used as a supplement to current minimally invasive surgical methods, enabling unparalleled access to sick tissues for biopsy analysis or therapeutic applications. The tissue samples were extracted from a pig bile duct using microrobots with star-shaped grippers that can reach small conduits in the body. Additionally, controlled navigation inside the eye of a living rabbit was performed in an initial proof of concept using magnetic microrobots. A magnetic coil system permitted the exact navigation of the untethered magnetic microrobots in the posterior eye area, despite the fact that this technology has not been shown directly for a surgical operation. Biopsy applications, in the end, offer fertile ground for more nanorobotics research since the success of these applications is dependent on the robot's capacity to physically modify its surroundings and the robot's controller's ability to recover the robot. Both of these issues have received far less attention than propulsion.

PERSPECTIVES FOR THE FUTURE

The field of medical nanorobotics has made significant progress. However, before nanorobots may be used in real-world therapeutic settings, a number of obstacles and challenges must be overcome. The purpose of the in vivo model is not only to assess the platforms' therapeutic performance, but also to detect clinical risk, as assessing off-target impacts of nanorobots is just as important as assessing efficacy. Indeed, there is a gap between medical nanorobotics' ideals and realities, since science fiction's legacy has established the mental bounds of what to anticipate long before scientists could. To address in vivo safety issues, the production of the nanostructure engines must be improved, with specific emphasis for material biocompatibility and degradation.