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Living Machines v/s Engineered Nanotech: A New Era in Drug Delivery Systems

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Abstract

Nanotechnology is changing the field of drug delivery by providing more targeted, efficient and personalized therapies. Two of the most promising advancements in drug delivery are xenobots, which are living machines engineered to perform specific tasks and nanorobots, which are synthetic microscopic devices designed for precise medical purposes, In this review, we see the potential of xenobots and nanorobots in enhancing drug delivery systems. By comparative analysis of xenobots and nanorobots will give us the suitable approach for precise medication. Discussing how each can be harnessed for targeted therapies, improved bioavailability and reduced side-effects. Xenobots bring unique advantages in biologically integrated systems, while nanorobots shine in precision control and scalability. When combined with artificial intelligence, these technologies have the potential for autonomous, real-time decision-making in delivering drugs. In conclusion, we highlight the future potential of these technologies to revolutionize drug delivery and drive precision medicine forward, stressing the importance of continued research and innovation to unlock their full capabilities

Introduction

Drug delivery technologies (DDTs) are making healthcare more precise and patient-focused. By guiding medications directly to where they're needed, they not only improve the effectiveness of treatments but also reduce the risk of side effects. These innovations allow doctors to see how drugs are working inside the body, giving them a clearer picture in real time. DDTs also make treatments personal, adjusting based on a patient's history and needs. Best of all, they achieve this while cutting down on dosages and costs, paving the way for more affordable, high-quality care. Xenobots are the living, swimming, self-powered living machines designed using a combination of biological tissues and computational algorithms which allows performing specific tasks from embryos of African clawed frog. Nanobots on the other hand are tiny machines typically ranging from 1 to 100 nanometers in size. They are built using techniques like self-assembly and top-down lithography, which involve designing them at the molecular level through computer simulations. The materials used in nanobot construction are carefully selected, often including carbon-based molecules or DNA.

However, it is crucial to address safety, ethical, and environmental concerns to ensure that nanotechnology is deployed responsibly and sustainably in healthcare applications.

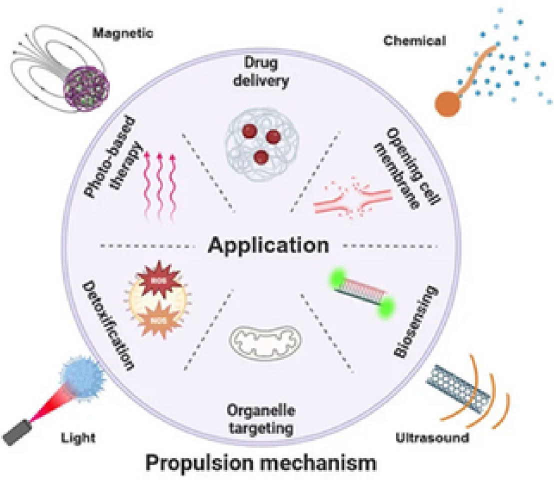

Fig 1 – Intracellular applications of nanorobots.

Adapted from- Tang, D.; Peng, X.; Wu, S.; Tang, S. Autonomous Nanorobots as Miniaturized Surgeons for Intracellular Applications. Nanomaterials 2024, 14, 595. https://doi.org/10.3390/ nano14070595

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Xenobots in Drug Delivery

Development and Mechanism:
Xenobots are made from the cells of the African clawed frog (*Xenopus laevis*). The process starts by extracting pluripotent stem cells from the embryos, which are capable of transforming into different types of cells. These cells are then separated and combined to form a uniform group. Computational algorithms are used to design Xenobots by simulating different shapes and behaviours, helping scientists create structures that can perform specific tasks.

The steps to develop Xenobots include:

- **Cell Harvesting:** Stem cells are taken from early-stage embryos of *Xenopus laevis*. Stem cells are the foundation of Xenobot technology because they provide the raw material necessary to create versatile, functional, and biologically compatible systems. They have unique ability to self – renew, differentiate and organization.
- **Cell Aggregation:** The harvested stem cells are grouped together to form tissue masses. This step mirrors the natural process of tissue formation, where cells communicate and organize themselves into cohesive units.
- **Shaping and Assembly:** Although Xenobot shapes are computationally designed, the physical tissue derived from stem cells must be manually sculpted to match these designs. Using microsurgery tools, such as electrodes, scientists precisely cut, assemble, and refine the tissue to create structures capable of executing the intended functions, like movement or cargo transport.
- **Functionalization:** Certain cell types, like ·cardiac cells, are added to give the Xenobots movement and the ability to interact with their environment.

Xenobots work because of their biological components. They can move on their own, respond to their surroundings, and even repair themselves if damaged. Their movement is usually powered by the contraction of muscle-like tissues, which can be programmed to perform specific actions.

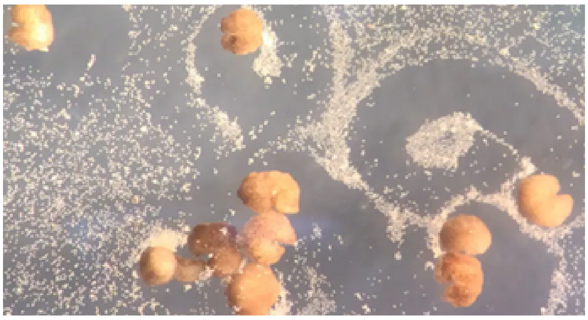

Fig 02 - Xenobots in a petri dish.
(*Credit: Douglas Blackiston and Sam Kriegman)*

Applications in Targeted Drug Delivery

Xenobots have a lot of potential in targeted drug delivery because they are biocompatible, can navigate tricky environments, and can be programmed for specific tasks. Some of their key applications include:

- **Smart Drug Delivery:** Xenobots can carry drugs and release them exactly where they're needed. For example, they can be designed to find cancer cells and deliver chemotherapy directly to the tumor, reducing harm to healthy tissues.
- **Environmental Cleanup:** While their main focus is medical use, Xenobots can also deliver agents to clean up toxins or pollutants in contaminated areas, showing promise in environmental cleanup.
- **Safe and Biodegradable:** Since they're made from living cells, Xenobots naturally blend into the body and break down harmlessly, lowering the risk of side effects compared to synthetic systems.
- **Controlled Drug Release:** Xenobots can respond to changes like pH or specific biomarkers, allowing them to release drugs only at the right place and time, making treatments more effective.
- **Helping with Healing:** In regenerative medicine, Xenobots could deliver growth factors or other agents to help repair tissues and speed up recovery after injuries or surgeries.

Xenobots bring an exciting new way to deliver drugs by using the benefits of living systems. As research progresses, their role in medicine and even environmental work will likely grow, offering creative solutions to some of our toughest challenges.

Nanorobots in Drug Delivery

Nanorobots are tiny devices engineered to deliver drugs with precision, offering innovative solutions in targeted therapies.

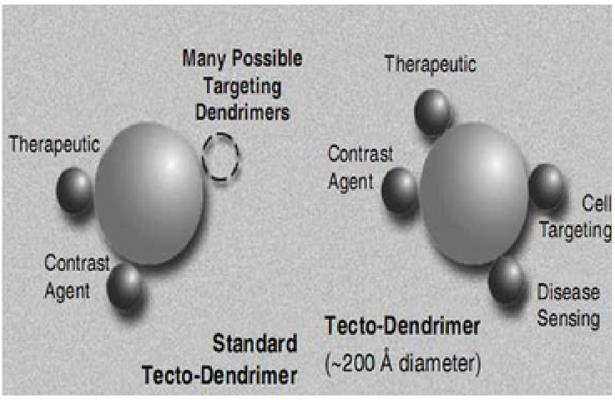

Fig 03 - The standard tecto dendrimer device
(Image courtesy of James Baker, University of Michigan)

Types and Designs of Nanorobots

- **Liposomes:** Lipid-based vesicles carrying hydrophilic and hydrophobic drugs, modifiable for targeted delivery.
- **Dendrimers:** Dendrimer nanorobots are nanoscale, highly branched structures designed for precise tasks like targeted drug delivery, diagnostics, and environmental cleanup. Their 3D framework allows customization to deliver drugs, sense abnormalities, or remove harmful· substances at the cellular level, offering high precision and minimal side effects.
- **Polymeric Nanoparticles:** Biodegradable particles providing controlled drug release responsive to stimuli.
- **Nanocapsules:** Core-shell structures protecting drugs and enabling precise release.
- **Magnetic Nanoparticles:** Magnetically guided particles for targeted drug delivery and imaging..
- **Carbon Nanotubes:** Cylindrical structures capable of delivering drugs or genes directly into cells.
- **Microswimmers:** Moving nanobots navigating fluids to deliver drugs to specific sites like tumors.

Applications in Drug Delivery

- **Cancer Treatment:** Nanorobots deliver chemotherapy drugs straight to tumour cells, reducing side effects by sparing healthy tissues.
- **Targeted Therapy:** With targeting ligands, nanorobots deliver drugs to specific cells, like cancer or infected cells, improving treatment precision.
- **Gene Therapy:** Nanorobots carry DNA or RNA to correct genetic disorders or introduce therapeutic genes directly into target cells.
- **Vaccination:** They enhance vaccine delivery by targeting immune cells, boosting the immune response and vaccine effectiveness.
- **Chronic Disease Management:** Nanorobots manage chronic conditions like diabetes by monitoring glucose levels and releasing insulin when needed.
- **Pain Management:** They provide localized pain relief by delivering painkillers directly to the source without systemic side effects.
- **Antibiotic Delivery:** Nanorobots target infections by delivering antibiotics to the infected area, helping tackle antibiotic resistance.

Comparative Analysis

- *Xenobots*: Can move, carry objects, and work together, adapting naturally to tasks due to their self-assembling nature.

- *Nanorobots*: Deliver drugs with high precision, interact with biological targets accurately due to their nanoscale size and customizable surfaces.

Scalability and Manufacturing Challenges

- *Xenobots:* Making Xenobots involves shaping biological tissues, which is time-consuming and hard to scale. Computational designs help but still need manual work.
- *Nanorobots:* More advanced manufacturing methods like chemical synthesis are scalable, but ensuring precision and uniformity is challenging, making mass production costly.

Feasibility in Clinical Settings

- *Xenobots*: Have potential in drug delivery and microsurgery but face issues like immune responses and lack of standardization.
- *Nanorobots:* Some are in clinical trials, capable of crossing barriers like the blood-brain barrier, but face challenges in stability and avoiding unintended effects on healthy tissues.

Ethical and Safety Concerns

- *Xenobots*: Ethical concerns include their creation and potential ecological risks if uncontrolled. Their moral status as living machines is still debated.
- *Nanorobots:* Risks include material toxicity and misuse in surveillance or weapons. Strict safety protocols and ethical regulations are critical.

Conclusion

Xenobots and nanorobots represent next-generation drug delivery systems, each with unique strengths. Xenobots are notable for their compatibility with biological systems, capacity for decomposition, and self-healing properties. making them ideal for adaptable tasks in biological environments. On the other hand, nanorobots are unmatched in precision and scalability, allowing for highly targeted and efficient therapies. While both technologies offer transformative potential in precision medicine, challenges like ethical concerns, safety risks, and manufacturing difficulties need to be resolved. Together, they signify a major step forward in creating personalized and effective healthcare solutions.

References

- Muthukumaran, G., Ramachandraiah, U., & Samuel, D. G. H. (2015). Role of nanorobots and their medical applications. Advanced Materials Research, 1086, 61–67. *https://doi.org/10.4028/www.scientific.net/AMR.1086.61*

- Kriegman, S., Blackiston, D., Levin, M., & Bongard, J. (2020). A scalable pipeline for designing reconfigurable organisms. Proceedings of the National Academy of Sciences, 117(4), 2305–2313. *https://doi.org/10.1073/pnas.1913788117*

- Tang, D., Peng, X., Wu, S., & Tang, S. (2024). Autonomous nanorobots as miniaturized surgeons for intracellular applications. Nanomaterials, 14(7),595. *https://doi.org/10.3390/nano14070595*