Research Output Journal of Engineering and Scientific Research 3(3): 5-8, 2024

ROJESR Publications Online ISSN: 1115-9790

https://rojournals.org/roj-engineering-and-scientific-research/ Print ISSN: 1115-6155

Synthetic Biology: Engineering Bacteria for Medical Applications

Odile Patrick Thalia

Faculty of Biological Sciences Kampala International University Uganda

ABSTRACT

Synthetic biology, a rapidly advancing interdisciplinary field, applies engineering principles to biological systems to create novel organisms with useful capabilities. This paper examines the potential of engineered bacteria in medical applications, focusing on advancements in genetic modification and metabolic engineering to develop bacteria capable of targeted drug delivery, disease diagnosis, and therapeutic interventions. The practical advantages of bacterial systems, such as low cost, rapid growth, and genetic malleability, make them ideal candidates for medical innovations. However, challenges in precision, safety, and ethical considerations demand robust regulation and containment strategies, particularly when considering applications in diverse socioeconomic contexts. As synthetic biology progresses, cross-disciplinary collaborations and ethical frameworks will be essential to harness its potential responsibly.

Keywords: Synthetic biology, Engineered bacteria, Genetic engineering, Medical applications, Drug delivery.

INTRODUCTION

Synthetic biology is an emerging interdisciplinary field that focuses on the design and construction of new biological parts, devices, and systems, as well as the redesign of existing biological systems for useful purposes. From a biological perspective, synthetic biology explores the fundamental properties of living systems, carrying out experiments to test and discover useful principles. From an engineering perspective, synthetic biology applies these principles, taking into account practical constraints and costs, to construct new kinds of cells and genetic circuits that do useful things. These breakthroughs are made possible by the convergence of advances in biology and the physical sciences, notably molecular biology, nanoscience, physics, and chemistry, but also information technology, mathematics, and engineering disciplines, as well as evolutionary and ecological thinking [1, 2]. Bacteria are of central importance in synthetic biology research as they are simple, inexpensive to grow, and capable of rapid cell division in inexpensive media. A common model organism is often used for fundamental research, and several of the techniques, devices, and systems developed in this organism have subsequently been ported to other relevant bacterial species. In both academia and industry, synthetic biology is studied by a wide variety of disciplines, including engineering, computer science, physics, and biology. Research in synthetic biology requires expertise in both biology and engineering. Thus, synthetic biology is regarded as an applied science because of its focus on applying the knowledge from engineering and biology, although it also arises from the more fundamental scientific question of what the minimal requirements for life are [3, 4].

Engineering Strategies for Modifying Bacteria

The engineering of bacteria represents a fundamental portion of the synthetic biology field that develops new organisms capable of performing desired tasks. Bacterial genomes can be precisely modified with the advent of various genetic engineering tools. Some of the available strategies for bacterial modification include the use of synthetic circuits to control the time- and location-specific expression of a gene or a combination of genes. The introduction of genes from other organisms can provide additional biological

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

functions to the bacterium, useful for new or enhanced bacterium-based applications. Metabolic engineering manipulates intracellular metabolic pathways, either by adding new enzymes or genes or by reconfiguring existing pathways to accomplish desired goals, such as higher production of target chemicals, rerouting resources, or global remodeling of metabolism. Synthetic biology has also been employed to improve the properties of bacterial strains for enhanced growth in adverse environments; for example, bacteria can be engineered to develop novel properties or mechanisms for growth even though they were initially engineered to have novel or extra-to-normal killing functions [5, 6]. Engineering bacteria has its challenges for researchers. The molecular tools used may lead to off-target effects or have unintended consequences, potentially causing harm. There is a systematic and incremental development in formulating guidelines and best practices in conducting studies on engineering bacteria. With the development of synthetic biology, multiple research groups are working together to standardize and optimize all the components and processes of engineering bacteria. Increasing awareness of these issues requires that robustness and prevention measures be put in place before, during, and after the bacterium is released to address health and ecological considerations [7, 8].

Medical Applications of Engineered Bacteria

Another medical application of engineered bacteria—besides producing therapeutics—is targeted drug delivery. Using factories that can produce tumor-killing drugs only inside the tumor, we could make more powerful drugs or reduce side effects. The target could even be dopamine by engineering the bacteria to respond to only its two signals. Using bacteria to generate biosensors may support disease detection and effective treatment in several strategies. First, using the bacteria to screen for biomarkers of the disease, and possibly its progression, may allow diseases to be diagnosed earlier. Second, some diagnostic tools could use bacteria to monitor health conditions in real-time, allowing diseases to be diagnosed earlier or reducing dependence on periodic check-ups. A further potential of engineered bacteria in medicine is in the treatment of infections. With the rise in antibiotic resistance, doctors are turning to bacteriophages to treat otherwise untreatable illnesses, as this could reduce concerns about using phages directly on the patient. Direct killing of pathogenic bacteria is another proposed therapeutic application of engineered bacteria. One way to accomplish this is to produce antimicrobials like colicins, which kill a variety of other types of bacteria. Genetically modified probiotics impart a health benefit by interacting with the microbiome rather than the individual. Such "modular" therapies could be formulated for multiple conditions; they could prevent opportunistic pathogens from colonizing the gut and have been shown to prolong the survival of sick mice. A novel technique for the delivery of therapeutic antigens for vaccination is being investigated. In cancer therapy, engineered bacteria have been designed to target and kill solid tumor cells [9, 10].

Challenges and Ethical Considerations

There are significant technical, economic, and manufacturing-related challenges to be considered. In addition, there are major ethical and regulatory considerations, particularly concerning the use of microorganisms as live medicines. Microbes can spread through food, water, and air, so what happens if they are released into the environment? This poses a very real biological safety risk to the general public, not just the patient. Containment strategies for genetically modified microorganisms have been under development for several decades, and the evidence from both laboratory and field containment of various GMMs shows that the actual risk of environmental release is extremely low. However, according to the precautionary principle, containment measures of whatever form should be applied with the assumption that there is a potential risk that is currently unquantifiable [11, 12]. The prospect of genetic modification often raises ethical concerns because it involves purposefully altering living organisms. There are, for example, debates over the manipulation and patenting of plant and animal germ lines as well as the cloning and genetic selection of human embryos. The general public is frequently ambivalent about the prospects for genetic engineering, and analyses of the ethical dimension of these practices are also highly controversial. Given these concerns, any use of engineered bacteria for medical purposes must be subject to robust regulation. Regulatory frameworks will have to meet current and future challenges of the innovation cycle, including early-stage research, clinical development, and manufacture, as well as post-marketing issues. These regulations are likely to be very complex, and appropriate public dialogue is therefore critical. The relationship between synthetic biology, innovation, and society is a complex and constantly evolving one, based on a long history of mid-twentieth-century caution surrounding the possibility of altering nature. Synthetic biologists have recently grappled with many of these issues in an international forum. Indeed, the motivations for creating a new field of synthetic biology include critical and ongoing examination of ethical practice in biotechnology as a societal issue of concern, in that it is

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

one among many factors that shape the course of innovation. Moreover, it is one in which synthetic biologists and members of the public need to engage in dialogue together. When considering these regulated and controversial risks in the context of low- and middle-income countries, for example, we are faced with ethical dilemmas like how to balance the engineered eradication of vectors or engineered medicines, such as these live bacterial therapies, with an appropriate level of robustness against misuse. The issue of promoting the safe use of this technology, particularly in the developing world where minimal infrastructure is more common, is key. The internal dialogues and control of use seek to address how social and governmental actors perceive, discuss, and deal with these responsibilities and choices. Public dialogue and the role of the public and civil society will have to change as the nature of some of these issues and choices does. Public and civil society do not have the capacity (nor the time or scientific knowledge) to understand certain risks and will need to work with a proactive state and industry in terms of regulation and control. Given the international biological and biotechnological revolution, these debates will likely need to take place across international forums [13, 12].

Future Directions in The Field

High-throughput screening methods could further expand bacterial engineering capabilities. Already, antibody screening techniques can identify proteins with a wide range of bioactivities. By expanding the tools of high-throughput screening to include small molecules, drugs, and other bio-based molecules, we could accelerate the discovery and optimization of engineered strains for mainstream applications. In combination with the introduction of cloud engineering, artificial intelligence and machine learning will much more likely be used to design optimal circuits and organisms based on huge data sets and hence structural patterns of existing biological systems [14, 15]. In the next years, we expect a significant expansion of medical applications of synthetic biology, including personalized medicine, antibiotics, tumor and viral targeting, nootropics, and other advanced biologic therapies, including tumor and biofilm targeting. Innovations in synthetic biology will continue to require multidisciplinary collaborations, such as those proposed for solving the bacterial enigma. Synthetic ecologies and synthetic production systems based on complex microbial communities with common or complementary consortia metabolic objectives, novel bioreactor designs, and process modeling will also contribute to better integration of synthetic biology in industrial biotech pipelines of advanced bio-based economy formulations. We believe that scientific research will face new sustainable directions in industrial and commercial fields, and additional engagement of ethical expertise may be needed to ensure artificial cells and synthetic biology progress in line with societal values. We believe that ongoing dialogue across stakeholders will serve to shape the future of synthetic biology and, in particular, that the next round of key technology outcomes will be defined through such a cross-community and inclusive approach [16, 17].

CONCLUSION

Engineering bacteria for medical purposes holds transformative potential in disease treatment, diagnostics, and targeted drug delivery. While synthetic biology has advanced rapidly, ensuring safety, precision, and ethical responsibility remains critical, especially regarding containment and the potential environmental impacts of genetically modified organisms. Future developments in synthetic biology will rely on high-throughput screening, artificial intelligence, and international collaboration to create safer, more effective applications. A proactive regulatory framework, coupled with public engagement and ethical discourse, will be pivotal in navigating the societal impacts of synthetic biology, ensuring its benefits are accessible and aligned with global health needs.

REFERENCES

1. Cubillos-Ruiz A, Guo T, Sokolovska A, Miller PF, Collins JJ, Lu TK, Lora JM. Engineering living therapeutics with synthetic biology. Nature Reviews Drug Discovery. 2021 Dec;20(12):941-60. mit.edu
2. Keating SM, Waltemath D, König M, Zhang F, Dräger A, Chaouiya C, Bergmann FT, Finney A, Gillespie CS, Helikar T, Hoops S. SBML Level 3: an extensible format for the exchange and reuse of biological models. Molecular systems biology. 2020 Aug;16(8):e9110. embopress.org
3. Dsouza A, Constantinidou C, Arvanitis TN, Haddleton DM, Charmet J, Hand RA. Multifunctional composite hydrogels for bacterial capture, growth/elimination, and sensing applications. ACS Applied Materials & Interfaces. 2022 Oct 12;14(42):47323-44. acs.org
4. Rodoplu D, Chang CS, Kao CY, Hsu CH. A simple magnetic-assisted microfluidic method for rapid detection and phenotypic characterization of ultralow concentrations of bacteria. Talanta. 2021 Aug 1;230:122291.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

5. Brooks SM, Alper HS. Applications, challenges, and needs for employing synthetic biology beyond the lab. Nature Communications. 2021 Mar 2;12(1):1390.
6. Tan X, Letendre JH, Collins JJ, Wong WW. Synthetic biology in the clinic: engineering vaccines, diagnostics, and therapeutics. Cell. 2021 Feb 18;184(4):881-98.
7. Tong CY, Honda K, Derek CJ. A review on microalgal-bacterial co-culture: The multifaceted role of beneficial bacteria towards enhancement of microalgal metabolite production. Environmental Research. 2023 Jul 1;228:115872.
8. Fadiji AE, Xiong C, Egidi E, Singh BK. Formulation challenges associated with microbial biofertilizers in sustainable agriculture and paths forward. Journal of Sustainable Agriculture and Environment. 2024 Sep;3(3):e70006. wiley.com
9. Nguyen DH, Chong A, Hong Y, Min JJ. Bioengineering of bacteria for cancer immunotherapy. nature communications. 2023 Jun 15;14(1):3553.
10. Lin D, Feng X, Mai B, Li X, Wang F, Liu J, Liu X, Zhang K, Wang X. Bacterial-based cancer therapy: An emerging toolbox for targeted drug/gene delivery. Biomaterials. 2021 Oct 1;277:121124. [HTML]
11. Andualem B, Seid A. The role of green biotechnology through genetic engineering for climate change mitigation and adaptation, and for food security: current challenges and future perspectives. Journal of Advances in Biology & Biotechnology. 2021 Jan 10;24(1):1-1. pacificarchive.com
12. Yue Y, Xu J, Li Y, Cheng K, Feng Q, Ma X, Ma N, Zhang T, Wang X, Zhao X, Nie G. Antigen-bearing outer membrane vesicles as tumour vaccines produced in situ by ingested genetically engineered bacteria. Nature Biomedical Engineering. 2022 Jul;6(7):898-909. researchgate.net
13. Canale FP, Basso C, Antonini G, Perotti M, Li N, Sokolovska A, Neumann J, James MJ, Geiger S, Jin W, Theurillat JP. Metabolic modulation of tumours with engineered bacteria for immunotherapy. Nature. 2021 Oct 28;598(7882):662-6. [HTML]
14. Kaczmarek JA, Prather KL. Effective use of biosensors for high-throughput library screening for metabolite production. Journal of Industrial Microbiology and Biotechnology. 2021 Dec;48(9-10):kuab049. oup.com
15. Gao J, Du M, Zhao J, Xu N, Du H, Ju J, Wei L, Liu J. Design of a genetically encoded biosensor to establish a high-throughput screening platform for L-cysteine overproduction. Metabolic Engineering. 2022 Sep 1;73:144-57. [HTML]
16. Hauer B. Embracing nature's catalysts: a viewpoint on the future of biocatalysis. Acs Catalysis. 2020 Jun 4;10(15):8418-27.
17. Baranwal J, Barse B, Fais A, Delogu GL, Kumar A. Biopolymer: A sustainable material for food and medical applications. Polymers. 2022 Feb 28;14(5):983.

CITE AS: Odile Patrick Thalia. (2024). Synthetic Biology: Engineering Bacteria for Medical Applications. Research Output Journal of Engineering and Scientific Research, 3(3): 5-8.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.